ASD-TDR-62-976

APPLIED RESEARCH AND DEVELOPMENT OF HIGH TEMPERATURE, HIGH POWER RF COAXIAL TRANSMISSION LINES

BROADBAND • LOW ATTENUATION • SEMI-FLEXIBLE

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ANDREW CORPORATION

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RESEARCH AND TECHNOLOGY DIVISION
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FOREWORD

This report was prepared by Andrew Corporation, 10500 West 153rd Street, Orland Park, Illinois, under Air Force Contract No. AF 33(616)-7389, Project No. 4156, and Task No. 415602. It was administered under the direction of the Systems Engineering Group, Research and Technology Division, Mr. L.A. Brewster (SEACA), Project Engineer.

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ABSTRACT

This report describes the applied research for materials and the development of two high temperature, low-loss, coaxial cables for operation in the -65 to 350°C and -100 to 825°C temperature ranges. These cables were developed primarily for use on aircraft, missiles and space vehicles.

The semi-air dielectric coaxial cables are produced by a continuous process which consists of spirally wrapping a quartz-filled teflon or braided silica insulator on the inner conductor. This construction was chosen because helically insulated coaxial cables provide the lowest losses over the widest band of frequencies.

The outer conductor is formed from accurately sized silver-clad Inconel or OFHC copper strip. As the tube is formed, the inner conductor assembly is fed into its center and this assembly is passed through a corrugating unit. The corrugator forms the helical configuration into the outer tube to provide flexibility and crush strength for the cable.

The inner and outer conductors use specially developed metallurgically bonded silver-clad materials that assure a high conducting level at the maximum operating temperatures with good mechanical properties. Inconel is used as the base material for the 825°C cable and OFHC copper for the 350°C cable.

Development of the dielectric was directed towards attaining a particular configuration with the lowest electrical loss, consistent with the mechanical, physical, and thermal requirements.

The two high temperature radio frequency transmission lines consist of cable, associated connectors, and pressurization accessories.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TABLE

SECTION I

INTRODUCTION

A need exists in aircraft, missiles and space vehicles, for low-loss, high temperature cables. These cables should be capable of efficiently transmitting all radio frequency energies for navigation, communication and counter measures. The high temperature requirements exists because the cable path may lead from the relatively cool areas of cockpit environments to the extremely hot external surfaces of a vehicle.[2]

R & D Exhibit WCLK 59-24 covers the requirements for a program of applied research for new cable dielectric and conductor materials leading to the development of two high-temperature, high power coaxial transmission lines consisting of cable, associated connectors, and pressurization accessories.

Two transmission lines were proposed for demonstration in the exhibit. These experimental models were based on theoretical considerations of available materials and findings of the "low-loss, high temperature, R.F. coaxial cable" study made by WADD.[1, 2].

For economical reasons, it was necessary that the program be constantly evaluated, to utilize commercially developed materials wherever possible, to select only the most practical approaches, and to conduct only the minimum amount of applied research necessary to provide the transmission line demonstration models, techniques, and engineering data.

Manuscript released by author for publication as an ASD Technical Documentary Report.

SECTION II

CABLE MATERIALS

A. CONDUCTOR MATERIALS

1. GENERAL

Electrical considerations: The type and design of conductors used in a coaxial cable play an important part in determining its electrical and mechanical characteristics. For coaxial cables, operating at radio frequencies, all electrical current carried by the cable is confined to thin layers located on the outer surface of the inner conductor and on the inner surface of the outer conductor. Although "skin depth" will very with frequency and the resistivity of the metals, for all practical purposes, all electrical current will be carried within 0.002 inches of the conductor surface. Anything that affects the surface resistance will have a direct effect on the attenuation of the coaxial cable[1]

It is necessary that the surface resistivity of the conductors be kept as low as possible. Surface resistance might be raised by oxidation, accompanied by formation of high resistance oxide scale, or from plated layers that are porous.

In selecting a conductor for operation at high temperature, initial resistance and assurance of a high conducting level at operating temperature are the major factors to be considered. Low conductor resistance is a requisite before, during and after exposure to elevated temperature[2]

Mechanical considerations: Metal below the "skin depth" has little or no effect on coaxial cable electrical properties, and may be considered from a purely mechanical standpoint. Here, strong metals may be used to provide greater strength at high temperature, or metals may even be removed, as in the use of tubular inner conductors, in order to make the cable as light as possible.[2]

Other mechanical considerations are:

a) Differential expansion between inner and outer conduction.
b) Creep at maximum operating temperatures and pressures.
c) Vibration endurance.
d) Thermal cycling.
e) Bonding or cladding.
f) Flexibility.
g) Weight, etc.

Fabrication considerations: In addition to the performance criteria, the selection of materials require the considera-

tion of production feasibility. For instance, it was desirable to utilize a material which could be obtained as thin-wall seamless tubing; but, if this preference were not consonant with other requirements, the material selected would require very good weld ability. Again, the material selected would have to permit the brazing of connectors at the cable ends. The cold-working characteristics of the outer tube would have to be sufficiently good to allow forming to the final corrugated shape without intermediate anneals. And if clad or plated materials were employed, the bond would have to withstand the forming operation as well as the service conditions (except in the case of an external plate, which might be applied after fabrication).

Practical considerations: Although any material which could be used in the high temperature cable (-100 to 825°C) would probably perform acceptably in the low-temperature cable, the converse is not true, and a broader range of materials must therefore be considered for the latter cable. The greater freedom of choice should be utilized to achieve both higher performance and easier fabrication.

Subcontracting: ARF Project 2204 was established to provide the Andrew Corporation with metallurgical assistance.[3] The tasks assigned to Armour Research Foundation were: First, to consider all of the interdependent requirements and render advice in the selection of the most promising metallic materials for each application; second, to perform laboratory experiments and evaluations as necessary to assist in the final choice of these materials; and third, to advise on methods of avoiding or overcoming problems which might arise in production of the two cables. These three aspects of the project will be considered in the following sections of this report.

2. MATERIAL SELECTION

a. Materials For -65 to 350°C Cable.

A maximum temperature of 350°C does not exclude from consideration either copper or aluminum, both of which are very attractive in many respects. However, it is certainly near the upper limit of serviceability for either in this application, and tests of actual cables were necessary to determine whether or not the mechanical property requirements could be met.

Aluminum offers two advantages over copper. It has sufficient oxidation resistance in air so that no coating or cladding should be required for protection, and it has a lower density. The latter implies that the effect of vibration on the dielectric spacer and the center conductor will be less severe, because of lower inertia.

Copper on the other hand, is more suitable as a base for electroplating and should be inherently capable of alloying to higher strength at 350°C because of its higher melting point. Aluminum alloys can be clad (for instance, with pure aluminum) but copper is more amenable to applications of a variety of techniques and materials.

It should be pointed out that interest is centered primarily on copper and aluminum, not because they are good electrical conductors, but because of good fabricability, reasonable cost, and moderately good mechanical properties. It would obviously be futile to specify materials which had a higher probability of satisfactory performance, but from which it was not feasible to produce a cable. On the other hand, if a material were satisfactory in all respects except electrical conductivity, it is likely that some means could be found to apply a conducting coating to the appropriate surfaces.

The decision was made to proceed with experimental fabrication of both aluminum and copper cables, deferring final selection until more data were available. After preliminary forming and welding trials with 1100, 3004, and 5050 aluminum alloys, 5050 was chosen for further work. It is generally weldable by all commercial procedures and methods, and has a room-temperature electrical conductivity of 50% IAS. Its formability is good, and its short time tensile strength at 600°-700°F is nearly as high as that of the strongest wrought aluminum alloys, with the exception of a few heat-treatable alloys which would probably lose their superiority in longer-time tests. It is therefore a good material on which to obtain data concerning the fabrication and performance of a prototype cable.

In the case of copper, it is not improbable that an alloy containing 0.10 to 0.15% Zirconium or 0.03 to 0.1% silver may be somewhat advantages with respect to strength at maximum temperature, although it is uncertain whether the advantage can be obtained over a 200 hour period. A decision

was made to use OFHC copper initially and at the same time investigate the higher strength copper alloys.[3]

b. Materials For -100 To 825°C Cable.
The choice of materials for use over the broader temperature range is very restricted. Iron-, nickel-, or cobalt- base alloys are the only real contenders. Any of these would require conducting coatings, and might be expected to offer difficulty in fabrication. Type 310 stainless steel was first investigated. Although it would apparently perform acceptably, we could not find anyone willing to supply us with silver-clad stainless steel tubing, and the silver-clad stainless steel strip could not be obtained in the annealed condition. It was decided to investigate Inconel. Inconel is one of the nickel-chromium-iron group of alloys. This group is characterized by great strength and resistance to oxidation at high temperatures. The thing we found most attractive was that it was possible to almost completely anneal Inconel without damaging the silver.

The coating materials investigated were gold and silver. Theoretically, copper could be used, but it was not seriously considered because it is vulnerable to oxidation under less than ideal conditions, and therefore lacks the safety factors inherent in gold or silver. Gold was rejected because, with little or no advantages over silver, it becomes very expensive in thick coatings, while thin ones are initially subjected to failure because of porosity and are rapidly destroyed by diffusion. With silver, we can afford to use a thick enough coating so neither porosity nor diffusion is a problem. The silver could be an electroplate or a cladding, but the latter is considered preferable with respect to bond strength uniformity, and freedom from defects. [3]

3. EXPERIMENTAL FINDINGS.

The experiments which were performed supplied information in three areas: oxidation resistance, diffusion, and weldability. Where possible, each experiment was designed to give data on more than one environment and material. It will be more convenient to report each experiment as a whole instead of treating each type of specimen separately.

a. Materials For -65 to 350°C Cable.
The characteristics of silver plate on copper were explored as follows. Three specimens of copper plated with silver were prepared; in one of these, the silver was plated directly on the copper; in the other two, a nickel flash was applied to the copper; and in one of the latter, a copper flash was applied over the nickel to facilitate the subsequent plating of adherent silver. Silver plating was initiated in a strike bath. The thickness of silver was about 2.5 mils on the first two specimens, and 3.5 mils on the third. All three specimens were sealed in Vycor with a partial pressure of argon, and were held at 350°C for 231 hours. Metallographic sections showed that in each case

diffusion was negligible (0.0001 in.). The presence of nickel as a barrier to interdiffusion of silver and copper is obviously not necessary.

Four specimens of silver-plated copper and several pieces of mica-filled teflon were sealed in a Vycor capsule with slightly less than one atmosphere of dry nitrogen. Two of the specimens were cut from the same pieces as those referred to in the proceding paragraph. One had a nickel flash under the silver, and both had exposed copper at the sheared edges. Of the other two specimens, one also had a nickel flash under the silver, and neither had copper exposed at the edges. The sealed bulb was placed in a muffle furnace for 209 hours at 350°C. During this time, the teflon acquired a light brown color, and the exposed copper tarnished slightly. When the specimens were removed from the bulb, it was observed that some blisters had formed on all plated surfaces. On the two specimens which were duplicates of those used in the preceding experiment, the blisters were so small that they were not immediately evident to the unaided eye except under very favorable illumination. They did not affect the adherence of the silver in adjacent areas, and the silver was not loosened at the sheared edges. Of the two, it was judged that the one with a nickel flash was somewhat better. The remaining two specimens, which were plated all over, showed more serious blistering, and the silver could be peeled extensively beyond the blisters. It is strongly suspected that this indicates an inferior electroplate; even in the better specimens, it is likely that the blisters formed as a result of normal porosity, which implies that cladding is to be preferred to electroplating.

When electroplated specimens similar to those above were exposed in air with similar temperature and time, the silver plate loosened completely because of oxidation of the copper.

The above results show that the presence of mica-filled teflon produced an oxidizing environment intermediate between air and argon in severity. From a subsequent experiment, it appears that water vapor evolved from the teflon was the oxidizing agent.

The next experiment was a 200-hr., 350°C exposure of 5 nitrogen-filled Vycor bulbs containing the following specimens:

1. 3004 aluminum alloy.
2. 3004 aluminum + quartz-filled teflon.
3. Quartz-filled teflon.
4. Quartz-filled teflon + nickel-flashed silver-plated copper + silver-plated copper.
5. Nickel-flashed silver-plated copper + silver-plated copper.

Examination of the bulbs and their contents showed that: (1)

all bulbs containing teflon had condensed water on the inner walls; (2) all three pieces of teflon turned black on the original surfaces of the strip, but not on cut ends; (3) the teflon swelled and showed cracks near the longitudinal axis; (4) the aluminum specimens were both unaffected except for a light, superficial discoloration; (5) the presence of teflon had no effect on surface appearance of the plated copper specimens; (6) the nickel-flashed silver-plated copper specimens appeared unaffected; and (7) the silver-plated copper specimens without a nickel flash showed blisters.

From these results, it is seen that the presence of teflon is not harmful to 3004 aluminum in a nitrogen atmosphere, even in the presence of water vapor at 350°C. This was confirmed by examination of a short length of corrugated aluminum tubing which had been filled with nitrogen, sealed with a piece of teflon inside, and exposed 200 hrs. at 350°C.

The observation of water vapor in the bulbs suggests that the teflon should be baked before use, both to preserve the electrical characteristics of the nitrogen and to give additional insurance against oxidation of the metal, particularly in the case of the copper cable.

Although the use of a nickel flash under the electroplated silver was beneficial, it does not follow that a silver cladding would require nickel underneath. The appearance of the samples indicated that the nickel merely improved the quality of the subsequent silver plate.

In another test, duplicate sets of specimens were exposed in air and in nitrogen for 200 hrs. at 350°C. Both sets were in glass bulbs, those with nitrogen being sealed. Each set consisted of five bulbs containing:

1. Filled teflon, type B (45% quartz).
2. Inner conductor, 0.002-in. silver cladding on copper alloy (0.03-0.1% Ag) tubing.
3. Filled teflon + inner conductor.
4. Filled teflon + corrugated type 5050 aluminum alloy outer conductor.
5. Filled teflon + inner conductor + outer conductor.

Examination of these specimens showed them to be in excellent condition. As expected, copper surfaces exposed to air developed a thin, non-adherent scale, but they were not seriously damaged. All aluminum surfaces showed some slight oxide film, part of which may have been due to the fact that the samples were not cleaned prier to exposure. As found previously, the teflon blackened on some surfaces in nitrogen, but not in air. (This blackening is assumed to arise from thermal cracking of some organic compound, probably a lubricant used in extrusion of the original teflon strip. In air this would volatilize or oxidize, rather than crack to leave

a carbon smudge). Some discoloration of the silver was evident on all specimens, and again this appears to be from contamination in handling (fingerprints appeared on some specimens). The integrity of the silver cladding was good, and it remained well bonded in all cases. No water was found in the sealed bulbs, and it may be said that the presence of teflon had no effect on the aluminum or the silver-clad copper.[3]

b. Materials For -100 To 825°C Cable.

Samples of silver-clad type 310 stainless steel sheet were prepared by the Andrew Corporation. The steel was 0.012 in. thick, the silver 0.002 in. thick, and some pieces had a 0.00002 in. plate of gold over the silver.

Exposure of the gold-plated samples to 825°C in argon for 20 minutes caused diffusion of the gold to such an extent that the characteristic yellow color was no longer present, although the color was not quite that of pure silver. In view of the rapidity of this process, the experiment was not continued to longer times. Instead, two new samples were sealed in glass with an argon atmosphere and held at 350°C. A change in the appearance of the gold was noticeable after about 12 hours, and the gold color was almost completely gone at the end of 65 hours. It was concluded therefore, that a thin plate of gold over the silver would be undesirable for either temperature, because the gold-silver alloy which forms would only increase the electrical resistivity of the conducting surface, and would not appreciably improve resistance to oxidation.

A specimen of the silver-clad stainless (without a gold plate) was exposed for 237 hours at 825°C in air. On the steel surface there was a thin, adherent, black axide, so thin that its extent could not be determined accurately, and beneath this, a very thin decarburized zone of about 0.00001 inch. The thickness of silver on the opposite side varied from 0.0017 to 0.0024 in., and beneath it there was an oxide layer 0.00017 to 0.0005 in. thick. The steel underlying the oxide had a decarburized zone 0.0010 to 0.0017 in. deep. Oxidation was clearly more severe on the silver-clad side; this is explained by the fact that silver transports oxygen at 825°C at a rate sufficient to cause substantial attack, but not fast enough to maintain the protective oxide film which normally limits the oxidation of stainless steel. In spite of the oxidation observed, the silver was not detached, and should have continued to function as a conductor. Although it is not intended that the silver-clad surface will be exposed to an oxidizing atmosphere, the ability to withstand such an environment gives additional assurance of performance under unpredictable circumstances. A specimen of the silver-clad stainless steel was held at 825°C for 200 hrs. in argon, after which a metallographic section was prepared. Diffusion was so slight that it could not be measured accurately by this method, but was surely less than 0.00002 in., which may be considered trivial for our purposes.[3]

4. CONDUCTOR DEVELOPMENT

a. Conductors for -65 to 350°C Cable.

1. Silver-clad OFHC copper tubing and strip: Metals & Controls, Inc., Attleboro, Mass., developed the tubing and strip for the -65 to 350°C cable. The following is a general outline, explaining in broad detail the process used:

Silver-clad OFHC copper tubing: Plater bar of OFHC copper and silver were metallurgically bonded under heat and pressure in a furnace without the use of solder (the silver and copper formed its own eutectic). This plater bar was then cross rolled from which a disc was cut. The disc was then drawn into a cup in a shell press - vertical press. It was then put on a horizontal drawboard and drawn to finish dimensions after several intermediate steps, such as annealing and cleaning. Using this technique, the following dimensions and tolerances were obtained:

O.D. = .350 $\pm$ .003
I.D. = .287 $\mp$ .003
Base Material = OFHC copper
Clad = .002" minimum silver on outside only
Minimum length = 65 feet
Seamless tubing

Silver-clad OFHC copper strip: See bonding process for silver-clad Inconel strip.

2. Silver bearing copper alloy (.03-.1% silver): silver is added to OFHC copper to raise the softening temperature and increase the creep resistance without any appreciable decrease in electrical conductivity.[7, 8, 13.] Metals and Controls Inc., Attleboro, Mass., initially tried to clad the silver bearing copper alloy (.03% silver). Over a period of approximately one year, six attempts were made to draw 65 foot lengths of silver-clad inner and outer conductor tubing using silver bearing copper as the base material. During this time, they fabricated three 65 foot lengths of inner conductor:

O.D. = .325 $\pm$.003
I.D. = .275 $\mp$ .003
Clad = .002" minimum silver on outside only
Base material = silver/OFHC copper alloy (.03% silver)
Minimum length = 65 feet.

However, on subsequent attempts, Metals & Controls was not successful in drawing the tubing without cracking the silver. They did not have any success with the outer conductor.

By this time, test results showed that OFHC copper

had adequate strength and the seam welded outer conductor construction looked very promising. Metals & Controls was instructed to change the base material to OFHC copper and supply silver-clad OFHC copper strip for the outer conductor.

3. Zirconium copper alloy: Zirconium copper alloy consists of OFHC copper and approximately .13% high purity Zirconium. It has higher strength at elevated temperature. At 350°C, it has 54000 PSI tensile strength as compared with approximately 20000 PSI for silver bearing copper (.03%) and 10,000 PSI for copper.[6, 7]

   Bridgeport Brass Company, Bridgeport, Conn., developed 65 foot lengths of soft temper Zirconium copper tubing:

   Outer Conductor Tubing:
   O.D. = 1.005" $\pm$ .003
   I.D. = .965" $\pm$ .003
   Minimum length = 65 feet

   Inner Conductor Tubing:
   O.D. = .325" $\pm$ .003
   I.D. = .255" $\pm$ .003
   Minimum length = 65 feet

   The Zirconium copper tubing was never fully evaluated because OFHC copper appeared to have adequate strength. The original plans were to plate the inside surface of the outer conductor and the outside surface of the inner conductor, but this did not prove to be feasible, especially the outer conductor.

   Another possibility was to develop silver-clad Zirconium tubing and strip. However, after the experience Metals & Controls had with trying to clad silver bearing copper, the idea was dropped.

   Metals & Controls and Bridgeport Brass were confident that silver bearing copper and Zirconium copper alloys could be silver-clad and drawn to the specified tubing dimensions, but it would take development time. If greater strength were required, it might be better to use silver-clad nickel. The outside surface would not require coating or cladding for oxidation protection.

4. Type 5050 aluminum: Aluminum Company of America was successful in drawing 65 foot lengths of seamless tubing:

   O.D. = 1.005" $\pm$ .003
   I.D. = .950" $\pm$ .003

   Pressure-temperature tests on cable using the type 5050

aluminum outer conductor showed that it did not have adequate creep strength at the maximum operating temperatures and pressures. (Figure 23)

b. Conductors for -100 to 825°C Cable.

1. Silver/Nickel/Inconel inner conductor tubing: Bridgeport Brass Company, Bridgeport, Conn., developed the inner conductor tubing for the -100 to 825°C cable. The following is a general outline, explaining in broad detail the process used:

 a) A disc composed of silver/nickel is used. The disc is metallurgically bonded using a patented process.
 b) The disc is cupped and drawn into deep drawn shells.
 c) Cupped and drawn material is redrawn to the final dimensions of 65' long x .160 x .027" wall. During this final step, a seamless Inconel liner is inserted within the composite. Thus the Inconel is pressure bonded to the nickel.
 d) Figure 16 is a photomicrograph of a silver clad nickel over Inconel tube showing transverse and longitudinal cross sections.

2. Silver clad Inconel and OFHC copper strip: Metals & Controls, Inc., Attleboro, Mass., developed both silver clad strip materials. Regardless of the type of materials involved, their PT bonding process performs as follows:

 a. Materials are abraded clean.
 b. Materials are bonded in the PT mill, using high pressure and no external heating. The material is then said to be in the green bond state. Therefore, to further mature the bond, the materials are sintered in Bell annealing furnaces. After the sinter annealing process, the materials are tolled to finished gauge with intermediate anneals performed as required. In the case of the silver clad Inconel material which requires a bright anneal, the last anneal is performed in a dry hydrogen atmosphere. The coils are then scrubbed as required and slit to width. By using this process, wide coils weighing up to 1000 pounds in continuous lengths can be achieved.

3. Silver clad type 310 stainless steel strip: Metals & Controls, Inc., initially developed silver clad type 310 S.S. using the PT bonding process. The temper of the clad strip was 1/2 to 3/4 hard. The stainless steel becomes work hardened during the cladding and rolling operations and it cannot be annealed because of the melting temperature of the silver. The annealing temperature of the type 310 S.S. is 1950-2100°F (1800°F minimum), whereas the melting temperature of silver is 1760°F. When the strip was formed

into a tube and corrugated, it was found to lack sufficient flexibility. In fact, the material was so hard that it sometimes cracked during the corrugating operation. Metals and Controls tried a new "warm body" technique which reduces the amount of cold work, but the strip still did not have the required temper for corrugating.

4. Silver clad type 310 stainless steel tubing: It was not possible to obtain silver-clad stainless steel tubing because the S.S. work hardens and intermediate annealing operations cannot be made because of the melting point of the silver. The tube drawing operation is much more severe on work hardening than strip.

B. DIELECTRIC MATERIALS

1. GENERAL

It is well known that helically insulated coaxial cables provide the lowest losses over the widest band of frequencies. Helical insulations suitable for coaxial cable insulation have been of a plastic nature such as polyethylene, polystyrene, and TFE fluorocarbon resin (teflon). Polyethylene and polystyrene can be used up to approximately 175°F; whereas, teflon is finding applications up to approximately 250°C.

The cable requirements call for two flexible low-loss insulating materials capable of operating in the temperature range -65 to 350°C and -100 to 825°C.

In selecting suitable dielectric materials for the two temperature ranges, the following characteristics were considered important: (1) Low dielectric constant and power factor over the specified temperature range - low electrical loss, (2) crush resistance - the ability to provide adequate support, (3) abrasion resistant - to enable handling during cable fabrication, (4) flexibility - to enable wrapping material around an inner conductor and bending after cable fabrication, (5) tensile strength - required during cable fabrication and at elevated temperature, (6) vibration endurance, (7) thermal stability - retention of electrical and physical properties.

2. MATERIAL SELECTION

a. Materials For -65 to 350°C Cable.

TFE-Fluorocarbon resin (teflon) has a combination of electrical and thermal properties unmatched by any other single material. Because of its excellent physical properties at high temperatures, teflon can be used continuously in cable applications up to 250°C, and intermittently up to 327°C, its melting point.

The potential use of teflon as an RF cable insulation for temperatures of 250°C or higher lies in its use with fillers such as quartz, silica, mica, and glass to improve its thermal and mechanical properties.

It is realized that by using fillers, some increase (over pure teflon) in losses will result; however, this is necessary in order to obtain a material having a lower coefficient of expansion, greater thermal stability, and greater mechanical strength. The filler content in proportion to the teflon should be kept as low as necessary to accomplish the mechanical and thermal requirements.

Preliminary investigation indicated that the following two

filled teflon materials looked promising and samples could be obtained for evaluation:

1. Fluorosint TFE resin: A mica filled teflon developed by the Polymer Corporation of Pennsylvania, Reading, Pa.

Electrical Properties*	Fluorosint	Teflon
Dielectric Constant	2.9 - 3.1	1.95 - 2.1
Power Factor	.0003 - .0005	.0003

Physical Properties*	Fluorosint	Teflon
Tensile Strength	2000 - 2500	1500 - 3000
Deformation under load -%		
(1200 PSI, 24 Hrs., 300°F	3 - 5	14 - 18
(1200 PSI, 24 Hrs., 400°F	4 - 7	22 - 30
Coefficient of Thermal Expansion of		
70-140°F	1.1×10^{-5}	6.9×10^{-5}
70-500°F	1.7×10^{-5}	9.7×10^{-5}
Specific Gravity	2.3 - 2.4	2.15 - 2.2

*Technical Bulletin BR-9; The Polymer Corporation of Pa.

It should be pointed out that the physical and electrical properties of compounded teflon depend on the additive, the amount of additive, uniformity of the blend, and molding and annealing techniques. The above published information is for molded parts of a given formulation. A mica-filled teflon section, extruded to a given cross section and with desirable physical properties, would probably have electrical and mechanical properties somewhere between the values given above for fluorosint and teflon.

2. "LD" TFE resin: A glass filled teflon developed by W. L. Gore & Associates, Inc., Newark, Delaware. The "LD" (Low Density) composition contains approximately 50% by volume of hollow glass spheres less than 300 microns in diameter. Basic properties of the "LD" teflon are as follows:*

    Dielectric Constant = 1.7
    Dissipation Factor = .0001 - .0003
    Density = 1.45 gm/cc
    Thermal Expansion = .55 times that of teflon
    Elongation = 200%
    Ultimate Tensile = 2000 PSI
    Flexural Modulus = 60,000 PSI

The glass in the hollow spheres is a boro-silicate glass. The glass constitutes approximately 10-12% of the volume of an average sphere. Properties of the solid glass are as follows:

    Dielectric Constant = 4.0
    Dissipation Factor = .001

The "LD" composition can be extruded in strip form, sintered, and swaged to desired cross section.

*This information was supplied by W. L. Gore & Associates, Inc., Newark, Delaware.

In the meantime, the Polymer Corporation of Pennsylvania was contracted to develop a quartz-filled Teflon dielectric to specific requirements. Very briefly, Polymer's experimental efforts involved investigating at least four independent sources of supply of electrical grade quartz. Samples of the finely divided quartz were obtained from these suppliers in as wide a variety of particle size and shape as was feasible. Filled Teflon compositions were made from these materials in a variety of filler contents. These materials were then screened for approximate coefficient of thermal expansion and for flexibility and recovery after bend and for dielectric constant and power factor. Samples of the most promising compositions were shipped to Andrew for further evaluation. The Polymer Corporation then produced 200 foot lengths of the formulation with the best physical and electrical properties.

Crane Packing Company, Morton Grove, Illinois agreed to, on a best efforts basis, fabricate 300 feet of Teflon impregnated quartz fiber cordage as follows:

1. Purchase General Electric Co. continuous length quartz fiber yarn (CFG yarn).
2. Have quartz yarn spun for braiding (approximately 30 to 35 strands per thread).
3. After the yarn is serviced, the starch-oil binder (organic) to be removed by heat treating - the material to be heat treated for optimum electrical properties without damaging the physical properties of the fiber.
4. Each thread to be individually Teflon suspensoid dipped. (Several impregnations may be necessary to achieve adequate Teflon saturation).
5. Approximately 16 to 20 threads to be tightly braided together, then sized, dipped again in Teflon suspensoid, and sintered to desired rectangular cross section.

This method of core fabrication was a complete failure. The finished core did not have any body and the cross section could not be maintained.

b. Materials for -100 to 825°C Cable.

Preliminary investigation indicated that the most suitable inorganic insulation for this application was a form of tightly braided quartz or silica cordage with sufficient density to provide a firm support for the inner conductor when helically applied.

Quartz or silica yarn, when properly processed (braided and treated), should produce the lowest loss helical insulation. These materials are not only delicate to handle, but are easily contaminated by dust, grease, and other substances that can seriously alter the electrical characteristics. Extreme care is required in the storing, handling, and processing techniques to minimize possibility of contamination.

Quartz or silica fiber fabrication techniques were directed toward attaining a particular configuration having the lowest loss, consistent with passing minimum flexibility, VSWR - bend, and shock and vibration requirements. It appeared likely that a "rope" helix could meet these requirements if properly constructed. General characteristics of the rope were believed to be as follows:

a) Round cross section
b) Tightly woven for "crush" resistance
c) Reasonably high tensile strength
d) Reasonable flexibility
e) Abrasion resistant
f) Little or no tendency to "shred" apart on flexing.

Three commercially available vitreous silica fiber materials were available: namely, (1) Quartz Fiber (staple filament); produced by Amersic Quartz Division of Engelhard Industries, Inc. (2) Quartz Fiber (continuous filament); produced by General Electric Lamp Glass Department, Willoughby, Ohio, and (3) Silica Fiber "Refrasil" (continuous filament); produced by H. I. Thompson Fiber Glass Company, Los Angeles, California.

Quartz yarn (staple filament); Engelhard Industries submitted samples of six different methods of braiding quartz rope. After examining them at some length, it was decided that the cordage was not dense enough and did not look promising enough for this application.

Quartz yarn (monofilament): General Electric produces a continuous filament quartz fiber. The basic yarn, which is commercially available, is essentially a 200-filament strand with a 1.0-Z twist. Individual filament diameter is .0004 inches.

CHEMICAL PROPERTIES

Quartz fiber yarns are composed of high-purity vitreous silica. A typical analysis of quartz fiber is given below:

Ingredient	Percent by Weight
$Si\ O_2$	99.97 +
Fe_2O_3	.001
$Ti\ O_2$	.0001
$Al_2\ O_3$	.0150
$Ca\ O$	.0032
$K_2\ O$	.0007
$Na_2\ O$	.0022
$Li_2\ O$	.0003

TABLE OF PROPERTIES

The properties of clear fused quartz are given below:

Density, gm/cc	2.2
Young's Modulus, psi	10×10^6
Average coefficient of thermal expansion, per °C (0 to 300°C)	0.55×10^{-6}
Softening Point, °C	1667

TABLE OF PROPERTIES (continued)

Annealing Point, °C	1140
Strain Point, °C	1070
Dielectric Constant/MC, 20°C	3.78
Power Factor/MC, 20°C	.0002
Loss Factor, 20°C	.0009

The quartz yarn also contains about 2%, by weight, of organic sizing compound, which is essentially a starch and oil type binder and lubricating agent. This binder may be removed by subsequent heat treatments at elevated temperatures.[29]

Refrasil yarn (monofilament): H. I. Thompson Fiber Glass Co. produces a continuous filament silica fiber. Refrasil yarn and cordages are capable of extended exposure to 1800°F without appreciable loss of their physical characteristics.

For short-time usage, Refrasil yarn and cordage may be taken close to their melting point, (approximately 3100°F) and still function as insulation.

TYPICAL COMPOSITION OF "REFRASIL" BRAND YARN AND CORDAGE

All "Refrasil" brand yarns and cordages contain 99% minimum silica with varying amounts of metallic oxides comprising the balance. A typical analysis is given below:

Ingredient	% by Weight
$Si\ O_2$	99.15
$Zr\ O_2$	0.05
$B_2\ O_3$	0.07
$Al_2\ O_3$	0.18
$Fe_2\ O_3$	0.03
$Mg\ O$	0.02
$Ca\ O$	0.04
$Ti\ O_2$	0.38
$Cu\ O$	0.002
$Na_2\ O$	0.08
$Cr_2\ O_3$	Nil
$Mn\ O$	Nil

Refrasil yarns and cordages contain a lubricant which has been applied to facilitate handling. In addition, some sizing remains on the unfired materials. This was applied during their original formation. In cases where it is necessary to remove these organics, heat cleaning is the only practical way. This is done by subjecting the yarn or cordage to an oxidizing atmosphere and a temperature of 1800-1850 for four hours followed by 2000°F for 15 minutes.

The above firing procedure is recommended if the best insulating properties are desired. Initial exposure to higher temperatures may cause the yarn to shrink too quickly and entrap carbon residue in the structure. If this occurs, continued firing under any condition has little effect on further removal.[30, 31]

3. EXPERIMENTAL FINDINGS.

a. Materials for -65 to 350°C Cable.

Sample lengths of the fluorosint section from the Polymer Corporation were placed in an oven at 350°C. After 200 hours the mica-filled teflon material became very hard and brittle. Any attempt to flex the material caused it to break. It actually changed from a flexible plastic-like material to a hard brittle material. Subsequently, it was tested at 300°C and did not appear to lose its flexibility.

Fifty foot lengths of cable were fabricated using fluorosint and "LD" teflon sections spirally wrapped around the inner conductor. A short length of each was placed in the oven at 350°C for 200 hours. A visual inspection of the cables showed radial cracks in the insulation every 1/4 to 3/8 of an inch. The cracks started on the exterior circumference of the insulation. The "LD" teflon did not become brittle like the fluorosint. (Figure 18)

In the meantime, the Polymer Corporation was developing a quartz filled teflon section. Table I shows preliminary screening test results for six powdered quartz fillers. The "spring back" results given in the table were obtained by bending a one quarter inch diameter rod of the filled teflon 127° around an 88 mil diameter mandrel and measuring the number of degrees it pulled back towards zero bend. Since the formulation of quartz power #111 (Charles Wagner Co.) gave the least spring back, processed well into beading and had good electrical properties, it was chosen for further work. No change of dielectric properties of any of the formulations was noted after aging for 200 hours at 350°C. [5]

The quartz power #111 filler was then investigated at 40, 45, 50 and 55% by volume in teflon. A wide variety of properties were determined. Results are given in Table II. Tensile strengths and elongations were run on pressed and free sintered material, rather than on processed 1/4" rod. Flexibility results were obtained by bending a 1/4" rod around an 88 mil diameter mandrel. The force necessary to bend the rod and the angle of the bend at the break, were recorded. All the rods bend 90° without breaking. The 45% by volume filler formulation was chosen as giving the best physical properties combined with an adequate safety factor in process ability. [5]

A batch of this material was then made and test processed by Polymer's Manufacturing Department. Equipment was designed to the specific processing characteristics of the material and short sections were made up to Andrew Corporation specifications.

Short lengths of cable were fabricated using the 45% quartz-filled teflon section and placed in the oven at 350°C. The insulation developed fine radial cracks.

Andrew Corporation then requested that new formulations be made up at 20, 30, 40 and 45% by volume and processed by Polymer's Manufacturing Department.

While Polymer was working on the various formulations, Andrew Corporation was experimenting with notching the insulator section so that it could be wound around the center conductor with far less stressing.

A number of test fixtures were constructed at Andrew Corporation for testing various dielectrics and configurations in the stressed condition. The samples and configurations tested are listed below:

1. Teflon (TFE) - skived
2. Teflon (TFE) - Paste extruded
3. Fluorosint - mica filled teflon (TFE) - extruded
4. "LD" teflon (TFE) - extruded - sintered - swaged
5. 20% quartz-filled teflon
6. 30% quartz-filled teflon
7. 40% quartz-filled teflon
8. 45% quartz-filled teflon
9. Item 4 above with notches toward inner conductor
10. Item 4 above with notches toward outer conductor
11. Item 8 above with notches toward inner conductor
12. Item 8 above with notches toward outer conductor

Of the unnotched materials, the 45% quartz-filled teflon lasted the longest without cracking; of the notched materials, the 45% quartz-filled teflon with the notches toward the inner conductor appeared to be the most promising. Quite a number of tests were made using 45% quartz-filled (two different processing techniques) and various notch sizes. See Figures 19-22.

Sample lengths of cable were constructed using the 45% quartz-filled teflon with notches toward the center. The insulation developed some fine cracks at bends where the insulation was stressed the greatest.

At the same time, Polymer was conducting stress-temperature tests on the filled-teflon after the following treatments:

a) Coating with teflon
b) Treating with Halo carbon oil
c) Bending before sintering
d) Lowering the sintering temperature
e) Treating with silicone
f) Heat aging at 350°C before bending

None of the above treatments were successful.

It was decided that any further improvement in the dielectric would have to be made in the geometry of the section and in fabrication of the cable. The objective being to reduce stresses as much as possible.

Attenuation measurements were run on fifty foot cables using teflon (TFE), fluorosint, and 45% quartz #111 dielectric:

Freq. MC	Wadd Spec's db/100'	Teflon (TFE) db/100'	Fluorosint db/100'	45% Quartz #111 db/100'
400	1	.96	1.04	1.55
1000	2	1.8	1.92	3.25
3000	4	3.1	4.22	7.8

From the above attenuation measurements, the dielectric loss was calculated and compared with the electrical information received from the manufacturer:

TEFLON:

Dielectric constant	-	2.0	)
Power Factor	-	.0002	) Mfg's. Information
Loss Factor	-	.0004	)
Measured Loss Factor	-	.0004	)

FLUOROSINT:

Dielectric Constant	-	2.9 to 3.1	)
Power Factor	-	.0003 to .0005	) Mfg's.
Loss Factor	-	.0009 to .0015	) Information
Measured Loss Factor	-	.00143	)

45% QUARTZ FILLED TEFLON:

Dielectric Constant	-	2.91	)
Power Factor	-	.0013	) Mfg's. Information
Loss Factor	-	.00378	)
Measured Loss Factor	-	.0034	)

Andrew Corporation requested further formulation work to see if the loss factor could be reduced to the level of the loss factor of Polymer's Fluorosint - or lower. The measurements taken on the resulting formulations are found in Table III. Crushed Vycor quartz #7900, Corning Glass Works, was found to have a low loss factor. On the advice of Andrew Corporation, the material was fired at 1000°F before use to get the very best electrical properties. The formulation processed well and the filler appeared satisfactory for further work. 250 feet of the 45% quartz #7900 was produced by Polymer's Manufacturing Department. The filled teflon section checked out very good dimensionally.

TABLE I

SCREENING TESTS ON QUARTZ FILLERS*

MATERIAL	DIELECTRIC PROPERTIES AT 1MC/S**				"Spring Back" Degrees	Processing Characteristics
	As Produced		After 200 Hrs. @ 350°C			
	Dielectric Constant	Power Factor	Dielectric Constant	Power Factor		
Crushed Vycor #7900, Corning Glass	2.42	.0002	2.42	.0002	67	Good
Quartz Powder #884, Whittaker, Clark & Daniel	2.55	.0006	2.55	.0005	67	Good
Quartz Powder #98, Charles A. Wagner Co.	2.46	.0002	2.46	.0007	Broke at 45	Good
Quartz Powder #111, Charles A. Wagner Co.	2.55	.0003	2.58	.0004	57	Good
Quartz Powder, 50-300 Mesh. General Elec.	2.54	.0005	----	----	67	Very Poor
Quartz Powder, 200-325 Mesh. General Elec.	2.48	.0004	----	----	67	Poor

* Formulated at 50% by volume in teflon

** Dielectric measurements were taken without silvering the sample surfaces. This gives somewhat low results for dielectric constant but has little effect on loss factor.

TABLE II

PROPERTIES OF TEFLON FILLED WITH QUARTZ #111

MECHANICAL PROPERTIES

% By Volume Filler	Density of/cc	Tensile Strength PSI	Elong-ation %	Flexibility °Bend	Flexibility Force, g	"Spring Back" Degrees	Dielectric Strength Volts/Mil	Processing Characteristics
40	2.15	940	20	90+	637	68	540	Excellent
45	2.12	850	5	90+	605	68	429	Excellent
50	2.07	950	0	90+	532	60	421	Excellent
55	2.00	640	0	90+	408	57	395	Poor

ELECTRICAL PROPERTIES

% By Volume Filler	Dielectric Properties at IMC/S: Dielectric Constant	Dielectric Properties at IMC/S: Power Factor	Coefficient of Thermal Expansion (80°F to 550°F) IN/IN/°F x 10^5
40	2.82	.0006	1.8
45	2.91	.0013	1.2
50	3.02	.0011	1.3
55	3.15	.0007	.86

TABLE III

DIELECTRIC PROPERTIES OF FILLED TEFLONS AT 1000 MC/S

FILLER	% BY VOLUME	DIELECTRIC PROPERTIES AT 1000 MC/S	
		DIELECTRIC CONSTANT	POWER FACTOR
Crushed Vycor #7900 Corning Glass Co. (As Received)	45	2.64	.0007
Crushed Vycor #7900 Corning Glass Co. (Fired at 1000°F before using)	45	2.51	.0006
Filler from regular Fluorosint	45	3.22	.0007
Quartz Powder #111	45	2.80	.0024
F-100-1/4 Quartz Fiber H. I. Thompson Fiberglas Co.	10	2.17	.0037

b. Materials For -100 to 825°C Cable

Bentley Harris Manufacturing Company of Conshohocken, Pennsylvania was confident that a tightly braided quartz rope could be fabricated using General Electric's monofilament quartz yarn.

A development program was set up to enable Bently Harris to purchase General Electric's quartz yarn, send yarn to a throwster to throw a dense core, and they in turn would provide a tight braid over the core.

Andrew Corporation received four 50 foot samples of quartz rope with different time-temperature heat treatments to remove the starch oil binder.

The length of quartz rope that had no heat treatment looked excellent. It had exactly the physical properties specified. The cross section was extremely dense and crush resistant and yet it was flexible enough to helically wrap around the inner conductor of the cable. It also had good abrasion resistance.

The other sample lengths had been heat treated at 1950°F for 5 seconds, 8 seconds, and 9 seconds respectively. The quartz rope sample that had been heat treated at 1950°F for 9 seconds was pure white, indicating that all the binder had been removed; however, the outer braid was broken in many places and the rope was extremely brittle.

The other lengths of quartz rope were dark gray in color indicating that all of the binder had not been removed. These samples were more flexible than the completely heat treated quartz rope but not as good as the rope that was not heat treated.

General Electric indicated that they had encountered the same problem after heat treating. They pointed out that heat treating at elevated temperatures results in a chemical reaction that reduces the strength of the fibers. After the binder is removed, the abrasion resistance is reduced and the weakened fibers break easily.

General Electric pointed out that everything in the starch oil binder is soluable in water and can be boiled out. They recommended three 1/2 hour boiling operations followed by drying. The yarn is then dipped in trichlorothylene solvent and dried again. The maximum temperature for drying is approximately 250°F.

Andrew followed the above procedure of removing the binder on the quartz rope sample that had not been heat treated and found that it was more flexible after the low temperature treatment. However, when the treated rope was placed in an oven at 1500°F, it took on a gray appearance at first indicating that all the binder had not been removed. After the

sample was removed from the oven it was very brittle and broke easily. Hess Goldsmith & Co., Inc., research and development laboratory, recommended a procedure for chemical cleaning quartz fibers and also suggested a chemical company (Rohm & Hass Chemicals) for obtaining information on enzyme desizing.

Andrew Corporation had the same results with chemical cleaning as reported for the boiling technique recommended by General Electric.

In the meantime, Andrew Corporation ran a comparison heat test using (1) dense quartz rope, and (2) not so dense Refrasil rope. Both samples were heat treated at 1600°F until the materials were pure white - indicating removal of binder. After they were removed from the oven, the Refrasil sample could be bent on a very sharp radius and it showed no tendency to break. The quartz rope broke very easily.

Andrew Corporation contacted H. I. Thompson Fiber Glass Company and discussed the cable requirements. H. I. Thompson indicated that they could supply a very dense Refrasil rope that had been heat treated at 1800-1850°F for four hours and that it would be flexible.

The sample length of Refrasil received was dense and reasonably crush resistant (it was not as dense and crush resistant as the quartz rope sample). The Refrasil rope was placed in an oven at 1600°F for 200 hours. At the end of this time it was still flexible.

Although the Refrasil rope was not as crush resistant as the quartz rope, it looked very promising. It was observed that the outer or over braid was not as tight on the Refrasil and after further investigation, it was learned that firing of a too tightly braided yarn may cause shrinkage to the point where the strands will actually break.

General Electric and Bently Harris were confident that they could provide a quartz rope construction that would be flexible after the binder was removed. Considerable time and effort went into varying the pitch and tightness of the overbraid. When they were satisfied that they had a construction that looked promising, a 100 foot sample was made up. The core and overbraid was not as tight as the original sample, but it was as good as the Refrasil rope. When the binder was removed, it was noted that the rope was a little more flexible but it still broke easily. This was difficult to understand because quartz fiber is supposed to be stronger and more flexible.

Test results seem to indicate that quartz fiber is stronger initially, but after exposure to elevated temperatures,

Refrasil is stronger and more flexible.

H. I. Thompson Fiber Glass Company has made great advancements toward improving (1) the purity of Refrasil, (2) fabrication techniques, (3) binder, and (4) binder removal.

Sample lengths of cable were fabricated using Refrasil and the test results showed that this material could possibly meet the electrical, thermal, and mechanical requirements. Further experiments with the quartz rope were discontinued.

C. CONNECTORS

1. GENERAL

In the design of the connectors, it is necessary that special emphasis be directed toward providing a termination that is electrically well matched to the cable and meets the full power, temperature, pressurization, vibration, and other requirements expected of the cable.

A flange type fitting is preferred since it would be the easiest to take apart in the event the connectors have a tendency to weld together - especially the 825°C connector. Pressurization is normally considered to be through the connector mounting area.

In addition to the above, the connectors should be as simple as possible, suitable for applications to any desired length, factory assembled, swivel type flanges, light as possible, and similar to connectors used for semi-flexible cables.

2. MATERIAL SELECTION

a. Connector for -65 to 350°C Cable.

Connector Outer Body: A number of materials were investigated for the 350°C connector and it was concluded that type 347 S.S. was the best connector material for this temperature range. Since elastomer type seals cannot be used at these extreme temperatures, the choice of connector material is controlled to a large extent by the material used for the metallic pressure seal.

Most of the metallic seal companies contacted recommended heat treated Inconel-X pressure seals for 350°C service and type 347 or 321 as being the best of the stainless steels for the flanges.

Inner Connector: The inner connector design is similar to those used to join EIA flanges. The contact resistance of a type 347 S.S. inner connector (no plating) was tested at 350°C with 7 amps of current flowing through it with the following results: (See Figure 142)

TIME	DATE	VOLTAGE DROP MILLIVOLTS	RESISTANCE MILLIOHMS	TEMP. °F
11:40	10/27/61	95	13.6	Ambient
11:45	"	70	10.0	650
11:50	"	40	5.72	640
12:00	"	38	5.32	640
12:05	"	29	4.14	640
12:25	"	29.5	4.21	640
12:45	"	22	3.14	645
1:15	"	27	3.86	645
4:15	"	29	4.14	655
7:35	10/28/61	27.5	3.93	655
4:00	"	29	4.14	675
8:20	10/30/61	28	4.0	630
2:10	"	31	4.43	640
8:20	10/31/61	31	4.43	670
4:55	"	31	4.43	655
8:25	11/1/61	31	4.43	660
8:25	11/2/61	31	4.43	660
1:30	11/3/61	32	4.58	655
5:45	11/4/61	26	3.71	Ambient

At the completion of the above test, the gap in the inner connector was adjusted and it was found that the voltage drop varied from 26 mv (closed) to 40 mv (1/8" gap). This test was conducted in air with no plating on the connector parts. The connector parts looked very good at the end of the tests. It was concluded that type 347 S.S. would be used for the inner connector. The parts will be silver plated for electrical conductivity.

Anchor Insulator: Dielectric materials such as glass-filled Teflon, mica-filled Teflon, quartz-filled Teflon, type-7900 Vycor, and NEMA grade G-7 were tested for this application. The anchor insulator, in addition to having good electrical properties, has to restrain the inner conductor movement relative to the outer conductor. During thermal shock, the force exerted on the anchor insulator by the inner conductor is quite large.

A fixture was devised for testing the various dielectrics in the oven at 350°C with weights hanging from the center of each. The type 7900 Vycor and NEMA grade G-7 were the only two that did not distort during a 200 hour test.

A connector with a type 7900 Vycor anchor bead was subjected to the specified vibration test. The glass did not break, but it did grind away on the metal and deposited a fine metallic powder on the face of the insulator. Since this is objectionable, the Vycor bead was not investigated further for this application.

A connector with a NEMA Grade G-7 anchor insulator was subjected to the same vibration test with no sign of mechanical failure or tendency to grind away on the metallic parts. This insulator looked promising enough to investigate further.

b. Connector for -100 to 825°C.

Connector Outer Body: Here again, the metallic pressure seal played an important part in the selection of the flange and body material. The metallic seal companies contacted were of the opinion that Inconel-X seals would work up to and beyond 825°C.

The Haskel Engineering Company recommended Inconel-X for the connector flange material at this temperature. They also recommended 19-9DL (Iron base super alloy)[12] for the hardware. 19-9DL has a slightly higher coefficient of expansion than Inconel-X, and this will prevent over-stressing the bolts at elevated temperatures.

A number of thermal shock tests were conducted using a modified Haskel Inconel-X seal[33] and Inconel-X flanges. The results were not consistent - the connectors either held pressure or completely lost pressure during thermal shock. Haskel Engineering pointed out that the Inconel-X seal was probably border-line for our low pressure application at 825°C. They recommended changing to Rene '41, a high temperature nickel-base super alloy.

Rene '41 seals are very costly. The reason being that the material is costly, the heat treatment is costly and the machining is very difficult. Further investigation by Haskel Engineering revealed that they could supply Waspaloy (another high temperature nickel-base super alloy) at approximately the same cost as Inconel-X in large quantities. Waspaloy has better spring properties than Inconel-X at 825°C, and it is easier to machine than Rene '41.[32]

Haskel Engineering indicated that the Waspaloy seals would work very well with the Inconel-X flanges.

Inner Connector: This inner connector design is a little different than the 350°C connector. Because of the very high temperature, it is desirable to keep the number of contacts to a minimum. Therefore, a separate inner connector is not used. One connector has a slotted male member whereas the mating connector has a female inner connector. The flange is not polarized.

Tests were conducted on various connector designs using Inconel-X. The Inconel-X slotted male member lost its spring properties at 825°C when the minimum insertion pressure was used. Various Waspaloy connector designs were

tested and they were border-line.

The best results were obtained with a slotted male member made out of Rene '41. Various combinations of slot widths, lengths, and number of slots were experimented with in an effort to determine the best design. The insertion pressure is very critical; if it is too great, the Rene '41 loses its spring properties.

All of the inner connector parts are made from Inconel-X with the exception of the male contact member.

Contact resistance tests could not be conducted on the Rene '41 and Inconel-X connectors in air because a high resistance oxide forms almost immediately at 825°C.

Anchor Insulator: Glass or ceramic insulators are the only dielectric materials available in this temperature range. An investigation turned up a relatively new high temperature ceramic material called Boron Nitride.[26] It is easily machined, and has good high temperature properties up to 3000°F.

Following are typical analyses of the solid as reported by the Carborondum Company[7]:

	Percent
Boron Nitride	97.0
Borix Oxide	2.4
Alkaline Earth Oxides	0.1
Alumina and Silica	0.2
Carbon	0.008

Electrical properties of Boron Nitride:

Dielectric Constant/1 MC	4.15 (Direction A)
	4.80 (Direction B)
Dissipation Factor/1 MC	0.0002
10 MC	0.00009

Some difficulty was experienced at first in electrically compensating the Boron Nitride anchor insulator. It probably had something to do with the fact that the dielectric constant parallel to the molding pressure is different than in the transverse direction.

The Boron Nitride anchor insulator was subjected to thermal shock and vibration tests. The results were excellent.

3. EXPERIMENTAL FINDINGS

a. Connector for -65 to 350°C Cable.

Connector and Pressure Seal: Two Inconel-X seals, manufactured by Haskel Engineering Company[33], were subjected to 30 cycles of thermal shock as specified. The seals were enclosed in type

347 S.S. connectors. It took one month to complete the 50 cycles. At the end of this time, approximately 720 hrs., the connectors had lost 7 and 10 pounds respectively from an initial 15 PSIG. The volume of gas in the system was equivalent to 50 feet of cable. This is considerably better than what was anticipated.

The pressure system will handle a leakage rate up to one pound in 24 hours, in 100 feet of cable for a one month period.

Inner connector: The contact resistance of a silver plated (.0015" thick) type 347 S.S. connector was measured before, during, and after 200 hours at 350°C in air with the following results: (See Figure 142)

TIME	DATE	VOLTAGE DROP* MILLIVOLTS	RESISTANCE MILLIOHMS	TEMPERATURE °C
4/30	11/13	2.2	.314	Ambient
8/20	11/14	3.3	.472	340
8/30	11/15	3.4	.486	360
9/45	11/16	3.3	.472	350
10/0	11/17	3.3	.472	350
10/0	11/18	3.4	.487	350
8/30	11/20	3.4	.487	350
8/30	11/21	3.4	.487	350
9/40	11/22	3.4	.487	350
9/47	11/22	2.3	.329	Ambient

*With 7 amps flowing through the circuit

After the above test, the contact surfaces were examined and there was no evidence of galling, blistering, or scaling. The initial force required to separate the contacts indicated that there was some binding. However, subsequent insertions showed that the insertion pressure did not change appreciably from what it was before the heat test.

The slotted male contact was then inserted into the cylindrical member and the contact resistance measured for various separations at the butting shoulder.

SEPARATION INCHES	VOLTAGE DROP MILLIVOLTS	RESISTANCE MILLIOHMS	TEMPERATURE °C
Closed	2.2	.314	Ambient
1/32	2.3	.329	"
1/16	2.4	.343	"
3/32	2.6	.371	"
1/8	2.8	.400	"
Closed	2.15	.307	"

Anchor Insulator: Three NEMA Grade G-7 anchor insulators were subjected to 50 cycles of thermal shock. The VSWR was

measured across the frequency band after 10, 20, 30, 40, and 50 cycles of thermal shock. The change in VSWR was very small, see Figure 36.

b. Connector for -100 to 825°C.

Connector and Pressure Seal: Thermal shock tests were conducted on a 5 foot length of cable with Inconel-X connectors and Waspaloy seals (Manufactured by Haskel Engineering Co.). There were two seals in the system and a pressure bottle outside with a capacity equivalent to 50 feet of cable. The following measurements were recorded:

TIME	DATE	TEMP. °C	PRESSURE PSIG	CONDITION (GOING INTO)	CYCLES OF THERMAL SHOCK
8:10	7/7/62	Ambient	18	Into Freezer)	1
10:10	"	-65	13.5	Out of Freezer)	
10:20	"	Ambient	16.	Into Oven)	
12:30	"	825	23	Out of Oven)	
12:40	"	Ambient	19	Into Freezer)	
2:40	"	-65	14	Out of Freezer)	2
2:50	"	Ambient	16.5	Into Oven)	
4:50	"	825	23	Out of Oven)	
		- - - - - - - -			
11:45	7/16/62	Ambient	10.5	Into Freezer)	
1:50	"	-65	9.5	Out of Freezer)	10
2:00	"	Ambient	10.5	Into Oven)	
4:00	"	825	16	Out of Oven)	
8:10	7/17/62	Ambient	10	---	

The average leakage rate is less than one pound in 24 hours.

Inner connector: Silver and gold plated connectors (Rene '41 male member, Inconel-X female member) were tested in a nitrogen atmosphere at 825°C for 200 hrs. Various thicknesses of plating were investigated to obtain the best electrical contact. The silver plated parts all had a tendency to fuse together and it was difficult to separate them after the oven test. On pulling apart, the surfaces were badly scored.

The gold plated connectors worked much better because the gold plating is much harder than the silver plating and it has a higher melting point. The seizing problem was also minimized by using a very thin plating.

The best results were obtained with 0.0003" thick gold and a 0.0003" nickel diffusion barrier. It is much easier to control the tolerances and hence the insertion pressure with the thinner plating.

The other Inconel-X conductor parts are silver plated (.0015" - .0020" thick).

The following VSWR measurements were made on one compensated Boron Nitride anchor insulator:

Frequency, MC	VSWR
1.0	1.04
1.4	1.08
1.8	1.08
2.2	1.04
2.6	1.04
3.0	1.025
3.4	1.02
3.8	1.03
4.2	1.04
4.8	1.06

D. GAS BARRIER

1. GENERAL

For air dielectric cables using flange type connectors, the usual practice is to supply a separate gas barrier rather than a pressure-tight connector. Also, it was decided that the chances of meeting the requirements were much better with a separate unit.

a. Gas Barrier For -65 to 350°C Cable.

After some experimenting with metallic type seals, it was concluded that this approach stood very little chance of success.

Some form of glass-to-metal or ceramic-to-metal seal looked promising. The following possibilities were investigated:

a) Moldable Supramich-a 620 BB ceramoplastic; the Mycalex Corporation of America.
b) Forsterite and Steatite; American Lava Corporation.
c) Glass to metal seal; The Carborundum Company.
d) Type 1723 Glass to metal seal; Vacuum Ceramics Inc.
e) Type 7070 Glass to metal seal; Vacuum Ceramics Inc.

The first four were dropped after a limited amount of investigation.

Vacuum Ceramics did some preliminary work with type 1723 and type 7070 glass-to-metal seals using Kovar. The type 7070 glass-to-metal seal gave the best results.

Andrew Corporation worked out an electrical design using the type 7070 glass. It was decided that the best approach was to make a glass-to-metal subassembly and later weld it in place between two flanges. (Figure 151)

Samples of the type 7070 glass-to-metal subassemblies were subjected to 50 cycles of thermal shock with no evidence of damage.

Four subassemblies were mechanically bolted between brass flanges to form a complete gas barrier and the VSWR of each assembly was less than 1.05 from 400 to 5000 MC.

The next step was to weld the glass to Kovar subassembly between two type 347 S.S. flanges. The welding operation was a success, and the VSWR of the assembly was as previously reported.

The gas barrier assembly was then subjected to the thermal shock test. It failed during the first cycle in going from cold to hot. It seems that the type 347 S.S. flanges (greater mass) forced the Kovar outer ring to expand with it. This put the glass in tension and caused it to crack.

The problem was discussed with Vacuum Ceramics and it was decided that the flanges would have to be machined out of Kovar.

Two new gas barriers were welded using Kovar flanges. The gas barrier assemblies were bolted between two type 347 S.S. flanges (Figure 24) and one side pressurized to 80 PSIG.

The first unit was subjected to 31 cycles and the second to 21 cycles of thermal shock with no evidence of damage, and the gas barriers held pressure. The tests were discontinued.

It became apparent while experimenting with the gas barrier, that the 1/8" thick glass was probably not going to be strong enough to withstand the mechanical abuse involved in connecting and disconnecting it to the cable.

The glass was increased to a 1/4" thickness and it made considerable improvement. The electrical and thermal properties were rechecked and the performance had not changed.

As an added precaution, while Vacuum Ceramics was working on the increased glass thickness, a bellows inner connector was designed. It was felt that this would compensate for slight misalignments at the connector. The connector inner conductor is anchored, and when the close fitting gas barrier flange mates with the connector flange, any misalignment forces are transmitted to the gas barrier inner connector (glass to metal seal). The bellows section gives just enough to relieve the stresses.

b. Gas Barrier For -100 to 825°C Cable.

It was very difficult to get anyone interested in working on a glass-to-metal seal for this temperature range. Vacuum Ceramics had indicated that they would be willing to try if they were successful with the 350°C seal.

They were successful with the 350°C glass-to-metal seal and did start work on a type 1723 glass-to-metal seal. There were considerable delays because Vacuum Ceramics was having problems obtaining the type 1723 glass from Corning Glass Works. The delivery was several months.

In the meantime, Vacuum Ceramics Inc. was purchased by C. P. Clare and the name changed to Clare Ceramics Inc. The new management was reluctant to spend time on development since they had a big backlog of production work.

Vacuum Ceramics did an excellent job on the type 7070 glass-to-metal seal. It is very possible that, after a transition period, they would be willing to work on this difficult sealing problem.

2. EXPERIMENTAL RESULTS

a. Gas Barrier For -65 to 350°C. Cable.

Two gas barrier assemblies were subjected to 25 cycles of thermal shock (See Figure 24 for test setup), and they

held pressure with no evidence of damage to the glass-to-metal seal.

Four gas barriers were also subjected to 25 cycles and 10 cycles of thermal shock in connection with testing the cable assemblies. Figure 27 shows the gas barriers attached to the cable.

The gas barrier, attached to a cable assembly, was subjected to the specified vibration test. The cable held pressure, and a visual inspection after the vibration showed no damage.

The VSWR of the final gas barrier design was measured with the plain and bellows inner connector. The results are shown in Figure 99.

The gas barrier assembly drawing is shown in Figure 151. This design meets all of the requirements.

E. PRESSURIZING

1. GENERAL

Pressurization of the cable assemblies is required to enable efficient, low-loss, semi-air dielectric to be used, yet provide for the high dielectric strength, maximum voltage rating, and freedom from altitude effects needed to permit operation with air-borne electrical equipment.

Different gases and different pressures effect the degree to which arc-over can be suppressed. General requirements for the gas, in addition to providing the desired corona and dielectric strength values, are as follows: Chemical and thermal stability for use at the extreme temperatures, inertness, non-toxic, resistance to decomposition under arcing conditions with no toxic by-products, compatibility with other materials, good heat transfer properties, and non-flammability.

Nitrogen is a very stable and inert gas and its boiling point is -195.8°C. It is attractive because of its stability and inertness, but its dielectric strength is slightly lower than that of air. Nitrogen could be used for both cables, but at a reduced dielectric strength and corona level.

2. GAS SELECTION

a. <u>Gas for -65 to 350°C Cable.</u>

E.I. DuPont, Freon Products Division, recommended that Andrew Corporation investigate Freon-116, Hexafluoroethane (C_2F_6), for a high dielectric strength gas in this temperature range.

Freon-116 is one of the most stable of all organic compounds and condenses only at very low temperatures (boiling point of -78°C). Its dielectric strength is about 2 to 5 relative to air. The higher ratios applying in non-uniform fields. Covective heat transfer properties are much better than those of nitrogen.[10]

b. <u>Gas For -100 to 825°C Cable.</u>

Preliminary investigation for a suitable gas in the -100 to 825°C temperature range concluded that there was no advantage in using Freon-14 over nitrogen since it has very little dielectric strength advantage (1.0 to 1.25 in a uniform field). It was later learned that most of the Freon gases possess higher dielectric strength in non-uniform fields.

Freon-14, Tetrafluoromethane (CF_4), has a boiling point of -128°C and it is the most stable of all fluorocarbon gases.

For even greater dielectric strength, E. I. DuPont recommended that a mixture of Freon-14/Freon-116 or Freon-116/

nitrogen be investigated. DuPont calculated a dew point curve for Freon-116/Freon-14 mixture, and to get a dew point of -100°C or lower, about an 80 mole percent of Freon-14 must be used. The addition of nitrogen (boiling point -195.5°C) to Freon-116 (boiling point -78.8°C) would have a more marked depression of dew point than does Freon-14. However, Freon-14 possesses higher dielectric strength than nitrogen in non-uniform fields and is probably superior to nitrogen as a diluent for Freon-116 at equal volume concentrations.

E. I. DuPont made up sample quantities of Freon-14 and an 86/14 (by volume) mixture of Freon-14/Freon-116 for test and evaluation.

3. EXPERIMENTAL FINDINGS

a. <u>Gas for -65 to 350°C Cable.</u>

Samples of the silver-clad OFHC copper inner and outer conductors and quartz-filled Teflon were bulbed in Pyrex and sealed with one atmosphere of Freon-116. The sealed unit was subjected to 200 hrs. at -65°C and 350°C. The sealed container was sent to DuPont's Chemical Department to be analyzed. Their Research Department reported that the decomposition of Freon-116 was about 0.0165% for the 200 hour exposure at 350°C or about 0.7% per year. Examination of the surface by Armour Research and DuPont showed no apparent change in the silver and a slight loss of reflectivity from the copper surface. The quartz-filled Teflon surface darkened as it did in the nitrogen atmosphere. This darkening of the quartz-filled Teflon surface in an inert atmosphere is caused by the lubricant used to extrude it to size. The Polymer Corporation has indicated that it will use a volatile lubricant in the future.

Dielectric strength and other electrical properties of Freon-116 are reported under "Cable Testing".

b. <u>Gas For -100 to 825°C Cable.</u>

Thermal shock tests on cable pressurized with Freon-14 showed no apparent change in the silver or Refrasil. There was not enough time to fully evaluate the chemical and thermal properties of Freon-14 and Freon-116/Freon-14 mixture in this temperature range.

The Freon-14 certainly looks very promising in this temperature range.

Dielectric strength and other electrical properties of these two gases are reported under "Cable Testing".

TABLE IV.

PROPERTIES OF GASES AT 760 mm Hg[1]

NAME	FORMULA	DENSITY LBS/CU.FT.	BOILING POINT °C	RELATIVE DIEL.STR.[2]	DIELECTRIC CONSTANT
Air	-	0.08018	-	-	1.000590
Nitrogen	N_2	0.07807	-195.8	1	1.000580
Hexafluoroethane	C_2F_6	0.356	-78.2	2.8	1.0020
Tetrafluoromethane	CF_4	0.242	-128	1-1.25	1.0006

1) See Table of Physical Properties; Reference 6

2) Dielectric strength relative to nitrogen in a uniform field.

CONT.

Dielectric strength versus pressure curves for each of the gases are given in Figure 82.

DISCUSSION OF TEST RESULTS

Although any of the inert gases shown in Figure 82 could be used in this temperature range, the nitrogen falls a little short of meeting the 6000 volts RMS (pressurized) requirement. The pressure regulating system is designed to maintain a minimum of 6 psig (± 1 pound) in the cable at all times (Pressure regulating system and specifications are given in Figure 146).

The Freon-116 high dielectric strength gas is probably the best for this application since it meets all the requirements and provides an extra margin of safety.

The other Freon gases and mixtures are shown for information. It may be desirable, for example, to use the same gas for cable "A" and "B" Freon-116 will not operate down to -100°C, therefore, either Freon-14 or Freon-14/Freon-116 mixture would have to be used. They both meet the dielectric strength requirements.

It was not possible to run a curve of corona extinction voltage versus pressure, for the various gases, because in most cases corona did not show up on the scope until breakdown. The few times that corona did occur before breakdown, the extinction voltage was within 1000 volts of the breakdown valve.

After studying the tests results shown in Figures 82 and 109, it appears that the slope of the curves for the Freon-14/Freon-116 mixture should be steeper than shown. The fact that this gas was tested last, it could be that the dielectric strength of the cable was reduced by the previous tests, since a 60 cycle/tester was used.

F. PRESSURIZING SYSTEM

1. GENERAL

The pressurizing system is to include pressure bottle, gauges, valves, and other fittings to provide for pressurization of these transmission lines for use in an air-borne application. It is intended that the pressurization accessories be used entirely within the relatively cool sections within the air or space vehicle next to the electronic equipment. The pressurization accessories shall be suitable for applications for use to 71°C. These accessories should be as light as possible, yet with sufficient capacity to provide for the maintenance of system pressure against normal leakage, in 100 feet of 7/8" cable for a period of one month. The pressurization equipment must meet the general requirements for equipment used in air-borne applications in accordance with specification MIL-E-5272.

2. PRESSURIZING REQUIREMENTS FOR -65 TO 350°C CABLE

The specifications state that the outer conductor must withstand pressures of 80 psig or maximum expected pressures, plus 50 per cent, whichever is greater, at a temperature of 350°C.

Pressure-Temperature tests on a length of 7/8" cable showed that the OFHC copper outer conductor operated in excess of 200 hours at 350°C with 100 psig pressure with no indication of physical distortion or pressure leak

The cable pressure was not increased above 100 psig at 350°C. It is possible that it could go higher, but 100 pounds is considered a safe pressure.

Based on the above, and dielectric strength requirements, it was decided that a pressure regulator should be used in the system to maintain a minimum of 6 psig (+ 1 pound). If the cable is pressurized to 6 psig (at sea level), and assuming no leaks, the following pressures will occur at the specified temperatures:

Temp °C	Absolute Pressure PSIA	Gauge Pressure PSIG	Comments
25	20.7	6	Ambient @ start
-65	20.7	6	Regulated
25	29.7	15.0	Back to Ambient
350	62.0	47.3	Maximum Pressure

At an altitude of 150,000 feet, the maximum gauge pressure will be 62.0 PSI. If a 50% safety factor is added, the outer conductor must withstand 93 psig. The cable successfully withstood 100 psig at 350°C.

Since the maximum theoretical pressure possible under normal operating conditions is 62 psig, a safety relief valve is

incorporated in the pressurizing system and it is set to release pressures in excess of 65 psig. This enables the outer conductor to operate with at least a 50% safety factor at all times.

Stewart-Warner Corporation, Southwind Division, was contracted to design and develop the pressurizing system to meet the cable requirements.

An absolute pressure regulator was originally specified, since it was not known for sure whether the compartment for housing the pressurizing equipment was to be pressurized or not.

As it turned out, Stewart-Warner could not locate an absolute pressure regulator that would meet the requirements and there was not enough time to develop one.

If the pressurizing equipment is not located in a pressurized room, it is possible for the pressure in the cable to go as low as 6 psia at 150,000 feet.

This is one reason for using Freon-116, since its dielectric strength at 6 psia is approximately 5000 volts (RMS).

3. PRESSURIZING REQUIREMENTS FOR -100 TO 825°C CABLE.
A 22 foot length of 3/8" cable coiled on a 32" diameter was subjected to the following pressure-temperature test:

Initial Pressure PSIG	Max. Pressure @ 825°C PSIG	Max. Pressure @ 825°C after Hrs. Indicated	Pressure After Return to Ambient Temp.	Time @ 825°C Hours
30	118	(Leak Found At Connection Input)		20.5
35	141	138	34.5	
40	150	150	40.0	24
45	173	171	44.5	48
50	187	177	47.0	96
55	214	180	43.0*	22

* No leak was found in the cable after it was returned to room temperature.

Based on the above tests, it was decided that the same 6 psig pressure regulator would be used. The following pressures will occur at the specified temperatures, assuming no leaks:

Temp. °C	Absolute Pressure PSIA	Gauge Pressure PSIG	Comments
25	20.7	6	Ambient @ start
-100	20.7	6	Regulated
25	35.6	20.9	Back to Ambient
825	131.5	116.8	Max. Pressure

At an altitude of 150,000 feet, the maximum gauge pressure will be 131.5 PSI. If a 50% safety factor is added, the outer conductor must withstand approximately 197 PSIG at 825°C. The cable successfully withstood 214 PSIG at 825°C.

Here again, an absolute pressure regulator would be preferred. The dielectric strength of this cable using Freon-14 and pressurized to 6 psig (sea level) is 4000 volts (RMS). If the pressure regulator is located in a pressurized compartment, there is no problem.

It is possible that at some later date, an absolute pressure regulator could be incorporated into this system.

4. PRESSURE TANK CAPACITY

The standard leakage rate for air dielectric cables is one pound drop starting at 20 psig in 24 hours for 100 feet of cable. This leakage rate amounts to 1305 cubic inches for 30 days. If we add the volume of the cable (627 in^3) and the volume of the cylinder (96 in^3) taken down to -65°C, the total volume is 1305 plus 1435 or 2740 cubic inches (free air).

If this quantity of air were put in a 96 in^3 tank, the pressure at room temperature would be 420 psig. If the pressure bottle has an initial pressure of 1000 psig, there is a safety factor of approximately 2.4 times. The maximum pressure the tank would see at 71°C would be approximately 1185 PSIA.

The 96 cubic inch tank with an initial pressure of 1000 psig should be adequate for this application.

SECTION III

CABLE FABRICATION

A. GENERAL

HELIAX is produced by a continuous process with equipment specially designed and built for this manufacturing operation. Essentially, the process consists of winding an insulator strip onto the inner conductor, then forming accurately sized sheet stock into a tube around the cable core, welding the tube and corrugating it all in one continuous operation. The finished product is a continuous, flexible, air dielectric coaxial cable.

Inner Conductor Taping Machine: This machine is used to clean and straighten the inner conductor and apply the helix section about it in a uniform manner. Looking at Photograph 147, in the foreground is the taping head which rotates about the inner conductor. Beyond this, the large horizontal ring is the capstan which pulls the inner conductor through the straightening, cleaning and taping equipment. All the equipment is tied together mechanically to give positive dimensional relationships. At the end of the line is the takeup unit which coils the inner conductor assembly on the drum. This unit maintains constant tension between the reel and the capstan. Photograph 148 shows a front view of the taping head.

Stripwelding Machine: The strip welding machine, shown in Photograph 149, is used to splice lengths of outer conductor strip together so that continuous lengths of cable can be sheathed. The machine consists of a payoff, a welding unit, a shear and a takeup. All strip is passed through this machine and put onto large spools for use in the wellmantle machine.

Wellmantle Machine: In the foreground (Figure 150, Top Photograph), the strip is shown entering the stock straightner and passing into the forming rolls to be shaped. As the tube is formed, the inner conductor assembly is fed into its center and this assembly is pulled through the machine by means of the capstan. The corrugator located at the rear forms the helical configuration into the tubing to provide flexibility and crush strength for the cable. The takeup unit shown in Figure 150, (Bottom Photograph) winds the finished cable on the reel.

B. FABRICATION OF CABLE FOR -65 TO 350°C. (CABLE "B")

1. Cable Construction

Cable Dimensions:

Major O.D. of Outer Conductor:	1.00"
Minor I.D. of Outer Conductor:	0.785"
Pitch of Outer Conductor Corrugation:	0.283"
Pitch of Quartz-filled Teflon section:	1.2875"
O.D. of Inner Conductor:	0.350"

Cable Materials:

Outer Conductor:	Silver-clad OFHC copper strip* (.002" silver/.018" OFHC copper); Formed and seam welded to give a 1.00" O.D. tube (silver clad on inside). After the cable is fabricated, a 0.0005" ductile nickel plating is applied to outer surface
Inner Conductor:	Silver-clad OFHC copper seamless tubing* (Silver clad on outside only); .350" O.D. x .287" I.D. with a minimum of 0.002" silver clad on the outer surface.
	*The silver clad is metallurgically bonded to the OFHC copper strip and tubing.
Insulation Strip:	Quartz-filled Teflon (TFE); cross section 0.235" x 0.150" (notched); spirally wrapped around the inner conductor with a constant pitch of 1.2875".

2. CABLE FABRICATION PROBLEMS

Inner conductor assembly: Heat tests conducted on experi mental cable indicated that the quartz-filled Teflon section had to be spirally wrapped around the inner conductor with little or no tension if radial cracking at 350°C was to be prevented.

Notching the dielectric section made it possible to bend the section around the inner conductor without excessive circumferential stresses. However, when the tension in the taping spool was reduced to a minimum, it was not possible to feed the inner conductor assembly into the outer tube without upsetting the helix. A constant pitch is required for good VSWR.

It takes 2.37 feet of dielectric section per foot of inner conductor to apply the helix section with little or no tension (1.278" pitch). For a reasonably good VSWR, the required material is 2.0 feet per foot of inner conductor. Less dielectric is required at increased tension because the material is stretched.

A number of techniques were investigated to solve the cracking problem. The dielectric was heat aged on a small diameter spool at temperatures up to 300°C. The section was then wrapped around the inner while it was still warm. The cable was then placed in an oven at lower temperatures,

approximately 250°F, for as long as one week.

Stress relieving the quartz-filled Teflon by either or both of these techniques did not completely eliminate the cracking problem at 350°C. The transition temperature of Teflon is 327°C, and its tensile properties are very poor.

The 65 foot lengths of silver-clad OFHC copper inner conductor tubing were spliced to give one continuous length. This helps to reduce scrap and makes it possible to fabricate electrically better cable. The quartz-filled dielectric can also be spliced in long lengths. The maximum unspliced length at the present time is 250 feet.

Outer conductor forming and seam welding: The forming, seam welding and corrugating operation was accomplished with the same tooling and equipment used for fabricating Andrew HELIAX. The major effort here was to determine the correct welding current for a good weld. The seam weld tested very good from a mechanical standpoint. Pressure tests show that the weld did not leak at 350°C and 100 psig.

Dielectric Section: A special notching fixture consisting of a Nylon nest and carbide blades was developed for notching the quartz-filled Teflon. The dielectric section is abrasive and care must be exercised to prevent metal adhesion.

Outer Conductor Assembly: After fabrication of the cable, it is cut in 50 foot lengths or less as required. The cable lengths are sealed and pressurized and a 0.0005" ductile nickel plating is applied to the outer surface for corrosion protection.

C. FABRICATION OF CABLE FOR -100 TO 825°C (CABLE "A")

1. Cable Construction

Cable Dimensions:

Major O.D. of Outer Conductor:	0.490"
Minor I.D. of Outer Conductor:	0.375"
Pitch of Outer Conductor Corrugation:	0.180"
Pitch of Refrasil Insulation:	1.55
O.D. of Inner Conductor:	0.160

Cable Materials:

Outer Conductor:	Silver-clad Inconel strip* (.002" Silver/.018" Inconel); formed and seam welded to give a 1/2" O.D. tube (silver clad on inside only). Pitch of corrugation on outer conductor is 0.180".

Inner Conductor:	.002" Silver/.006" Nickel/.019" Inconel composite seamless tube with a 0.160" O.D.; the silver is metallurgically bonded to the nickel and the Inconel tube is mechanically bonded to the silver/nickel tube. *The silver is metallurgically bonded to the Inconel strip.
Refrasil Rope:	The overbraided core has a maximum uncrushed outer diameter of 0.150"; the rope is spirally wrapped around the inner conductor with a constant pitch of 1.55".

2. CABLE FABRICATION PROBLEMS

Inner conductor assembly: Many difficulties were encountered in trying to spirally wrap the Refrasil rope (round cross section) around the inner conductor. The biggest problem was the twisting. The twist would build up until the Refrasil rope broke. The planetary winding head for the taping machine was modified, a new feed-off spool with an improved adjustable brake along with a modified pulley arrangement at the feed-on point made it possible to apply the helix without twisting or breaking.

It was also observed that for a given diameter inner conductor there was a minimum pitch that could safely be used without breaking the Refrasil fibers or rope. With a 1-1/8" pitch, as the tension was increased (to obtain a good tight inner assembly for low VSWR) the fibers in the overbraid would start to snap and sometimes the rope would break.

It was found that with a 1.5" pitch, the Refrasil could be tightly wrapped with very little if any damage to the overbraid.

Increasing the pitch to 1.55" moved the pitch reject frequency down to approximately 3400 MC. The cable can be used above the reject frequency.

Another problem involved feeding the inner conductor assembly into the outer. Any abrasive action caused an accumulation of small vitreous fibers or dust. A conveyor type guide was developed to feed the inner conductor assembly into the outer conductor. It worked very well, resulting in very little drag on the Refrasil. The pitch appeared to be undisturbed, and as a result, there was a substantial improvement in VSWR.

Here again, the 65 foot lengths of inner conductor are

spliced together so as to obtain good VSWR and minimum scrap. The Refrasil rope comes in minimum lengths of 100 feet. It would be desirable to obtain longer lengths or else develop a good splice.

Outer Conductor Forming and Seam Welding: A complete set of tools for forming Inconel strip for seamwelding 1/2" diameter tubing had to be made using Ampco Di Bronze. The forming tools used for copper caused excessive scratching and galling. A new roller type corrugating nut was designed and built for corrugating the high strength Inconel tubing.

The initial forming, welding and corrugating was done with plain bright annealed Inconel strip. The first shipment of silver-clad Inconel had a darkened surface which turned out to be an oxide layer which had formed during the annealing operation, and it was very abrasive. This presented a wear problem since the closely fitted ring guide is made of Di Bronze.

The silver-clad Inconel strip formed, welded, and corrugated very well until the ring guide became oversized.

The unused material was shipped back to Metals and Controls to be pickeled and brushed. The reworked material was considerably less abrasive. However, the welding current required to give a good weld was different.

The next shipment of clad strip was bright annealed to insure complete freedom from surface oxidation. The strip was shipped in two lots and it was observed that one surface was darker than the other. The two materials did not weld the same. In fact, the darker surface gave the best weld.

Metals and Controls only explanation was that a different bright annealing technique may have been used since the strip was made at different times.

The surface condition of the clad strip appears to be very important. The specifications will have to be tightened to make certain that we always get the surface condition that gives the best weld.

Dielectric Section: The best electrical properties were obtained when the Refrasil rope was heat treated at 825°C for 1/2 hour just before the cable was fabricated. The moisture picked up by the Refrasil during cable fabrication can be removed by passing dry air through the cable. The cable is then sealed and pressurized with dry nitrogen or other gas.

SECTION IV

TESTING OF PROTOTYPE CABLE MATERIALS

A. GENERAL

The following represents the findings of an investigation carried out by Armour Research Foundation for the Andrew Corporation.[4] It concludes the examination and evaluation of the prototype cable materials as received and after exposure to specified atmosphere-temperature conditions.

B. MATERIALS FOR -100 TO 825°C CABLE

Two Vycor bulbs were prepared, containing specimens as follows:

1) Silver-clad Inconel seamless tubing - corrugated; 1/2 in. OD x .020" wall with a minimum of .002 in. silver on the inside surface only.
2) .002" silver/.006" nickel/.012" Inconel composite seamless tube with a .155" OD; the silver is on the outside. (These dimensions were later changed to: .002" silver/.006" nickel/ .019" Inconel with a .160" OD; nevertheless, the following tests would apply to either size tube).
3) Heat treated Refrasil rope with a .150" OD *uncrushed).

One bulb was left unsealed, while the other was sealed with an internal atmosphere of nitrogen at approximately atmospheric pressure. Both were then held at 825°C for 216 hours. It was noted that the inside of the unsealed bulb, near the specimens, was slightly frosted, while the sealed bulb was clear. The reason for this is not known. Macroscopically, the specimens appeared as follows.

Air-exposure: The inner conductor was oxidized and blackened on the inside, and silver white but blistered on the outside; the corrugated outer conductor was slightly oxidized (blackened) on the outside, and silver white but frosty (roughened) on the inside; the Refrasil showed a slight tan discoloration in places, but seemed otherwise unaffected.

Nitrogen exposure: The Refrasil was unchanged. The inner conductor was blackened on the inside, and unchanged on the outside (smooth and silvery-white). The outer conductor was darkened somewhat on both surfaces, except for the weld line on the inside, which was silvery along the center. The darkening of the silver surface appears to be a superficial effect.

The macroscopic appearance of the specimens can be understood with the aid of a series of photomicrographs. Figures 1 and 2 show several representative sections of the as-received materials. It may be seen in Figure 2 that the bond between the nickel and Inconel is mechanical rather than metallurgical, and the nickel, together with the silver, can be stripped from the base metal. However, it does not seem that this should be a cause for concern. The thickness and uniformity of the silver plus the nickel appear to be adequate for the purposes it is to serve.

Figures 3 and 4 show the condition of the outer and inner con-

ductor specimens after a 216 hour exposure in nitrogen at 825°C. No change is evident.

Figures 5 and 6 show similar specimens after exposure to air at 825°C for 216 hours. On both specimens there is an oxidized zone below the silver; the latter is, however, still intact. It should be remembered at this point that the cable is not expected to be subjected to air internally during service. The fact that conducting surfaces can be maintained under such extreme conditions is merely a supererogatory characteristic which provides an extra factor of safety.

The roughening of the silver surfaces of the specimens exposed in air is explained by the formation of thick oxide layers underneath, and in the case of the inner conductor, some slight separation at the silver oxide interface. Formation of the underlying oxides was not brought about by defects in the silver coating, but by oxygen transport as a solute in the silver.

With the above facts in mind, it is possible to consider a plausible explanation for the fact that the silver surface of the outer conductor exposed in nitrogen was discolored, whereas all other silver surfaces, whether exposed in air or nitrogen, were white. In the first place, the fact is obvious that the cause of discoloration could not have been solely in the specimen or in the atmosphere, but must have resulted from interaction between specimen and atmosphere. Secondly, there is no reason to assume that the silver initially present on the outer conductor is any different from that on the inner conductor. (Neither discolors in air, which contains nitrogen as well as oxygen). Therefore, it must be assumed that a difference between the silver on inner and outer conductors developed during exposure --- and only in the bulb containing "pure" nitrogen, i.e., with no more than a trace amount of oxygen as impurity. The only reasonable explanation of such a difference is that it arose by diffusion of base metal outward through the silver. (It will be recalled that there is nickel under the silver on the inner conductor, but Inconel under the silver on the outer conductor). The diffusing element could be either iron or chromium, or both; from the color, chromium seems the more probable. Only trace amounts of oxygen would be required to form a very thin oxide of either iron or chromium on the silver surface.

The absence of discoloration of the silver on the outer conductor in air is accounted for by the fact that the silver can dissolve large quantities of oxygen from the air, so that oxidation of the chromium or iron can occur rapidly at the silver-Inconel interface, after which the chromium oxide (or iron oxide) cannot diffuse outward through the silver, and acts as a barrier to the diffusion of additional chromium or iron, while the silver rapidly dissolves additional oxygen from the air. Under these conditions, the site of oxide formation cannot be the external surface of the silver.

This rather lengthy consideration of the nature of the discoloration should not impute undue importance to the presence of such a film. Because of the extremely slight thickness of the film, it is not expected to have practical significance.

To summarize briefly, it may be said that the performance of the materials was very satisfactory in these tests, and no difficulties with them are foreseen.

C. MATERIALS FOR -65 TO 350°C CABLE

Four Vycor bulbs were prepared, containing specimens as follows:

Bulbs No. 1, 2, and 3

1) Silver-clad OFHC copper seamless tubing; .350" OD x .287" ID with a minimum of 0.002" silver on the outer surface only.
2) Silver-clad OFHC copper seamwelded tubing - corrugated; 1" OD x .020" wall with a minimum of 0.002" silver on the inside surface only.
3) Quartz-filled Teflon section.

Bulb No. 4

1, 2, & 3 above plus one silver-plated type 347 S.S. connector (assembled).

All metals parts except the connector were cleaned with detergent, then rinsed, and dried with acetone. The bulbs were sealed as follows: Nos. 1 and 2 with approximately one atmosphere of Freon 116; No. 3, unsealed; No. 4, sealed with approximately one atmosphere of nitrogen. One of the bulbs containing Freon 116 was sent to E.I. DuPont for analysis. The other three bulbs were treated 200 hours at 350°C and air cooled.

The appearance of the specimens exposed in nitrogen was unchanged except that the Teflon darkened on air surfaces, and a few blisters developed on the connector.

The connector did not easily slip apart after exposure, indicating that some bonding by diffusion between the mating silver surfaces may have occurred. However, the two parts could be separated with considerable force applied. The mating silver surfaces were intact and appeared unaffected.

Metallographic sections of the specimens after exposure are shown in Figures 10-15. There is no evidence of damage in the specimens exposed in nitrogen or Freon 116. A thin layer of copper oxide may be seen underneath the silver on the outer conductor exposed in air (Figure 10). Such an oxide layer is not clearly discernible on the air exposed inner conductor (Figure 11); this is evidently due to an interface phase present in the inner conductor as received. It is probably a silver-copper alloy formed by diffusion during manufacture.

On the basis of both macroscopic and microscopic evidence, the oxidation resistance of these specimens was satisfactory and in accord with expectations.

D. SUMMARY

Samples of various materials for coaxial cable were subjected to exposures of 200 hr. in nitrogen, in air, and in Freon-116. The different materials were divided into two groups, one of which was tested at 350°C, and the other at 825°C, according to the performance requirements of the cable for which each was intended. Examination of the specimens showed that all behaved as expected with respect to oxidation resistance and integrity of cladding. The evidence gave no reason to doubt the suitability of the materials for the intended applications.[4]

SECTION V

TESTING OF PROTOTYPE CABLE

A. **GENERAL**
All testing was conducted in accordance with specification MIL-C-17, except as otherwise noted in R & D Exhibit 59-24.

B. **CABLE FOR -65 TO 350°C**

1. Insulation Resistance, Capacitance, Velocity, Characteristic Impedance, and Attenuation measurements versus temperature and time were conducted on one 50 foot length of cable with connectors and gas barriers as shown in Figure 134. The test equipment setups for making these measurements are shown in Figures 135-138, and the measurements are recorded in Tables 5 and 6.

   Curves of attenuation versus frequency for the following conditions are given:

   a) Attenuation vs frequency @ room temperature (Figure 40)
   b) " " @ 100°C (Figure 41)
   c) " " @ 200°C (Figure 42)
   d) " " @ 300°C (Figure 43)
   e) " " @ 350°C (Figure 44)
   f) " " After 46 Hrs. @ 350°C (Figure 45)
   g) " " After 68 Hrs. @ 350°C (Figure 46)
   h) " " After 115 Hrs. @ 350°C (Figure 47)
   i) " " After 139 Hrs. @ 350°C (Figure 48)
   j) " " After 163 Hrs. @ 350°C (Figure 49)
   k) " " After 187 Hrs. @ 350°C (Figure 50)
   l) " " After 210 Hrs. @ 350°C (Figure 51)
   m) " " @ Room Temp. after 210 Hrs. @ 350°C (Figure 52)
   n) " " Gas Barrier removed-At Room Temp. After 210 Hours at 350°C (Figure 53)
   o) " " Gas Barrier replaced after cleaning - At Room Temperature after 210 Hrs. At 350°C (Figure 54)
   p) " " @ -65°C (Figure 55)

<u>DISCUSSION OF TEST RESULTS</u>

Insulation Resistance: Insulation Resistance tests conducted on an experimental cable showed that as the cable cooked at 350°C, the insulation resistance took a sharp drop. When the cable was purged, a white smoke came out. The smoke was condensed in a glass container and it turned out to be an oily liquid. After a short time, the smoking stopped and the insulation resistance was back to normal.

The problem was discussed with the Polymer Corporation and they indicated that the oily liquid was most likely the lubricant used to extrude the quartz-filled section.

For the prototype cable, the quartz-filled Teflon section was

TABLE V
Measurements of Cable "T"
Prototype Cable (50')

[illegible] Temperature Levels	Insulation Resistance Megohms/50' (TP 4.5.4) 600 Volts	Capacitance MMF/ft (TP 4.5.7)	Velocity Percent (TP 4.5.8)	Attenuation db/100' (TP 4.5.10) (See Note Below)
Cold Chamber @ -65°C	1×10^6	22.05	90.9	100 MC - .56 400 MC - 1.08 1000 MC - 2.2 2000 MC - 3.8 3000 MC - 5.8 4000 MC - 9.05 5000 MC - 11.78
Room Temp. @ 20°C	5×10^6	22.1	90.8	100 MC - .491 400 MC - .983 1000 MC - 2.16 2000 MC - 3.48 3000 MC - 5.11 4000 MC - 8.98 5000 MC - 10.22
Furnace @ 100°C	6.5×10^5	22.15	90.7	100 MC - .648 400 MC - 1.02 1000 MC - 2.5 2000 MC - 3.38 3000 MC - 5.11 4000 MC - 8.35 5000 MC - 10.55
Furnace @ 200°C	6×10^3	22.1	90.7	100 MC - .556 400 MC - 1.03 1000 MC - 2.95 2000 MC - 3.74 3000 MC - 5.35 4000 MC - 8.06 5000 MC - 10.37
Furnace @ 300°C	3.3×10^2	22.25	90.2	100 MC - .687 400 MC - 1.375 1000 MC - 2.55 2000 MC - 4.03 3000 MC - 5.64 4000 MC - 7.86 5000 MC - 10.7
Furnace @ 350°C	2.2×10^3	22.6	90.3	100 MC - .623 400 MC - 1.278 1000 MC - 2.55 2000 MC - 3.78 3000 MC - 5.27 4000 MC - 8.02 5000 MC - 9.37
Room Temp. After 210 Hrs. @ [illegible]°C	1×10^7	22.73	90.7	100 MC - .622 400 MC - .982 1000 MC - 2.05 2000 MC - 3.68 3000 MC - 5.5 4000 MC - --- 5000 MC - 7.8

NOTE: Cable Assembly includes, 50 feet of cable with connectors plus a gas barrier on each end

TABLE VI
Measurements On Cable "B"
Prototype Cable (50')

[illegible] 300°C	Insulation Resistance Megohms/50' (TP 4.5.4) 600 Volts	Capacitance MMF/ft (Optional)	Velocity Percent (Optional)	Attenuation db/100' (TP 4.5.10)
20	2.2×10^3	22.6	90.3	100 MC - .62[illegible] 400 MC - 1.278 1000 MC - 2.55 2000 MC - 3.78 3000 MC - 5.27 4000 MC - 8.02 5000 MC - 9.37
46	4.75×10^3	22.6	90.5	100 MC - .904 400 MC - 1.375 1000 MC - 2.52 2000 MC - 3.87 3000 MC - 5.27 4000 MC - 7.43 5000 MC - 8.64
68	5.65×10^3	22.7	90.5	100 MC - .68 400 MC - 1.32 1000 MC - 2.55 2000 MC - 4.2 3000 MC - 6.2 4000 MC - 7.5 5000 MC - 7.9
115	5.6×10^3	22.8	90.5	100 MC - .655 400 MC - 1.33 1000 MC - 2.71 2000 MC - 4.36 3000 MC - 6.33 4000 MC - 7.57 5000 MC - 8.09
139	5.7×10^3	22.7	90.4	100 MC - .635 400 MC - 1.39 1000 MC - 2.71 2000 MC - 4.32 3000 MC - 5.95 4000 MC - 7.17 5000 MC - 8.35
163	5.4×10^3	22.9	90.5	100 MC - .674 400 MC - 1.232 1000 MC - 2.69 2000 MC - 4.22 3000 MC - 6.3 4000 MC - 7.56 5000 MC - 8.7
190	5.8×10^3	23.0	90.5	100 MC - .687 400 MC - 1.36 1000 MC - 2.73 2000 MC - 4.28 3000 MC - 6.32 4000 MC - 6.92 5000 MC - 9.0
210	5.8×10^3	23.15	90.5	100 MC - .674 400 MC - 1.213 1000 MC - 2.85 2000 MC - 4.32 3000 MC - 5.9 4000 MC - 8.15 5000 MC - 8.9

heat treated on a spool for a short time at 300°C. The finished cable was allowed to cook in the oven at 250°F and then purged.

The cable was returned to room temperature and the tests outlined in Table 5 were conducted. The cable was not purged until the gas barrier was removed at the end of the series of tests.

The insulation resistance was reasonably constant except for a short time when it reached 350°C. It appeared that there was still some lubricant present. This is discussed in more detail under "Attenuation".

Capacitance: The measured variation in capacitance after 210 hours at 350°C was 0.63 MMF per foot or 2.87%.

Velocity: The variation in velocity after 210 hours at 350°C was 0.1%. The maximum variation in velocity over the temperature range -65 to 350°C was only 0.5%.

Characteristic Impedance: Using values of percent velocity and capacitance in MMF/ft, the characteristic impedance is calculated by means of the following formula:

$$Z_0 = \frac{1016}{(\%\ \text{Vel.})\ (\text{Capacitance in MMF/Ft})}$$

A curve showing the variation of characteristic impedance with temperature and time at 350°C is given in Figure 55a.

Attenuation: Referring to the attenuation curves Figures 40-55, it can be seen that the attenuation at the higher frequencies drops off after exposure at 350°C. The losses at the higher frequencies are mostly dielectric, and therefore a change in dielectric loss will show up more in the 3000 to 5000 MC range.

I t seems that all of the lubricant was not removed from the quartz-filled Teflon previous to cable fabrication. Referring to Table 5, the insulation resistance took a drop in the 300°C to 350°C temperature range. After 46 hours at 350°C, the insulation resistance went up (Table 6) and the high frequency attenuation went down.

After the 210 hour heat test at 350°C, the cable was brought back to room temperature and the attenuation was not too much different than the initial room temperature measurements.

However, when the gas barriers were removed, it was noted that they were coated with an oily liquid, mostly on the end where the pressure was released. The attenuation readings were repeated without the gas barriers (Figure 53), and after cleaning and replacing the gas barriers (Figure 54). In both cases, the high frequency attenuation went down a considerable amount.

The following is a comparison of attenuation readings taken from the curves:

Freq. MC	ASD Specs.	Before 350°C Heat Test	After 350°C Test Before cleaning Gas Barrier	After 350°C Test After cleaning Bas Barrier
400	1.0	1.05	1.15	1.05
1000	2.0	2.0	2.3	2.0
3000	4.0	5.0	5.5	4.5
5000		10.0	9.4	7.0

It would be a big step if the initial measurements (with no heat treating) were as good as the values shown above for "After cleaning gas barrier".

The following values of loss factor and power factor are based on cable measurements and cavity measurements:

Dielectric	Cable Measurements L.F.	Cable Measurements P.F.	Cavity Measurements L.F.	Cavity Measurements P.F.	Dielectric Constant
Teflon (TFE)	.0004	.0002	.0004	.0002	2.0
Teflon (FEP)	(.0014	.00067	.0013	.00062	2.1
	(.0018	.00086	.0018	.00086	2.1
Quartz-filled TFE before heat Treating	(.002	.0008	.00195	.00078	2.5
Quartz-filled TFE after heat Treating	(.0013	.00052	.0015	.0006	2.5

If the following precautions are taken before and during fabrication of the quartz-filled Teflon, it is very possible that the power factor can be reduced to less than 0.0005:

1) Heat treat the crushed Vycor fill for optimum electrical properties (up to 2000°F) just before mixing with Teflon.
2) Keep impurities out of mixture.
3) Use a volatile lubricant for extruding and possibly heat treat immediately to remove any traces of lubricant.
4) Use extreme care during storing, handling, and processing to minimize possibility of contamination.

The loss factor of the dielectric section is very important in rating the cable for average power at the high frequencies. The higher the losses, the lower the average power rating.

One last point should be made regarding the attenuation at -65°C (Figure 55) - The losses increase at the higher frequencies. These measurements were repeated a number of times to make certain. The losses at 5000 MC are higher at -65°C than at room temperature. It is rather certain that the Teflon

is not at fault. The only thing it can be is the crushed Vycor fill. The power factor of some glasses increase at lower temperatures and this may very well be the case here. These measurements were made before the cable was placed in the oven. The only other possibility would be the lubricant. This is not serious but it is worth mentioning since the losses did not go down as expected.

2. VSWR and Bend Radius
The VSWR of the 50 foot cable assembly used for the tests in (1) above is given in Figures 38 and 39.

VSWR and Bend Radius Tests on a 10' cable assembly were conducted and X-rays taken for the following conditions:

a) Straight length of cable with simple connectors (Figure 56)
b) Straight length of cable with connectors (Figure 57)
c) 20" diameter bend (Figures 58 and 91)
d) 15" diameter bend (Figures 59 and 91)
e) 13" diameter bend (Figures 60 and 92)
f) 10" diameter bend (Figures 61 and 92)
g) 7" diameter bend (Figures 62 and 92)
h) 5" diameter bend (Figures 63 and 92)

Sweep frequency technique was used from 500 to 3000 MC and slotted line method from 3000 to 5000 MC.

DISCUSSION OF TEST RESULTS

The VSWR curve in Figure 56 shows what the cable itself looks like without connectors. The simple connector referred to introduces very little mismatch across the frequency band - probably less than 1.02. The VSWR of the cable is under 1.15 up to 4000 MC.

The pitch of the helix (dielectric) was selected to place the reject frequency above 4000 MC as specified. From the curve it appears that it is approximately 4200 MC. The cable can be used on either side of the pitch reject frequency depending on what VSWR can be tolerated.

The VSWR, as would be expected, goes up when the high temperature connectors are used (Figure 57). The connectors show up mostly at the higher frequencies. The two connectors add four anchor insulators into the system and they are frequency sensitive. Figure 36 shows the VSWR of one anchor insulator. It is under 1.05 up to 5000 MC.

The VSWR of two connectors back-to-back (four insulators) is shown in Figure 37. The increased VSWR of the cable assembly in the 4000 to 5000 MC range is due to the connectors.

It is difficult to make a broad-band connector with a lower VSWR for this frequency range. If there were an application in the 4000 to 5000 MC range, the connectors could be improved for this smaller bandwidth. It might also be mentioned that the pitch

reject frequency can very easily be placed in the 3000 to 4000 MC range. This would improve the overall VSWR in the 4000 to 5000 MC range. The pitch of the dielectric would have to be increased to decrease the reject frequency and this in turn would reduce the dielectric loss and hence the high frequency attenuation.

The VSWR of the 20" diameter bend (Figure 58) is not much different than that of the straight length. The high point around 4200 MC is the reject frequency that didn't show up as much in Figure 57.

The VSWR at the high end (above 3000 MC) starts to increase with the 10" diameter bend and even then it is only a 1.1 increase (Figure 61).

Figure 63 shows that the cable can be used right down to a 5" diameter bend with small increases in VSWR.

It should be pointed out that the recommended bending radius is 10" or a 20" diameter bend.

X-ray photographs (Figures 91 and 92) show that the inner conductor is concentric, and there are no visual signs of kinks in the inner or outer conductor all the way down to a 5" diameter bend.

The VSWR performance of the cable and cable assembly is considered to be very good. It is possible that some improvement could be made in the connector VSWR.

3. Thermal Shock.

Two transmission lines with connectors and gas barriers were subjected to 10 and 25 cycles of thermal shock. The test was conducted in the following manner:

Each transmission line assembly five feet long was mated to firmly fixed receptacles in a heat chamber as shown in Figure 140. The transmission lines were cycled for two hours at 350°C, cooled for 10 minutes at room temperature, and placed in cold chamber at -65°C for two hours. The transmission lines were returned to room conditions for approximately 10 minutes and inner conductor continuity checked. This constitutes one cycle.

The following VSWR measurements and X-rays were taken:

Cable No. 1:

a) VSWR before thermal shock (Figures 64 and 65)
b) VSWR after 10 cycles of thermal shock (Figures 66 and 67)
c) VSWR after 10 cycles of thermal shock with gas barrier removed (Figures 68 and 69)
d) X-ray after 10 cycles of thermal shock (Figure 93)

Cable No. 2:

a) VSWR before thermal shock (Figures 70 and 71)
b) VSWR after 10 cycles of thermal shock (Figures 72 and 73)
c) VSWR after 25 cycles of thermal shock (Figures 74 and 75)
d) X-ray after 10 cycles of thermal shock (Figure 94)
e) X-ray after 25 cycles of thermal shock (Figure 95)

DISCUSSION OF TEST RESULTS

The average VSWR peaks of cable No. 1 after 10 cycles of thermal shock increased approximately 1.1 up to 4000 MC. Above 4000 MC, the peaks went up considerably higher (Figures 64-69). The VSWR test was repeated after removal of the gas barriers and it made a noticeable difference in the 4000 to 5000 MC range. Except for a film of oil on the gas barrier, it is not certain what caused the high VSWR. When the gas barrier was cleaned, it appeared to be in good condition.

The X-ray photograph of cable No. 1 (Figure 93) shows that the center conductor at the bend moved off center slightly. A visual inspection of the inside of the cable at the bend revealed that the quartz-filled Teflon section was slightly compressed toward the inside of the bend. A radial crack in the insulation was also observed.

Other than the above, the cable appeared to be in good condition.

Cable No. 2 gave similar results after 10 cycles of thermal shock. The average VSWR peaks went up a little higher (about another 1.1) after 25 cycles of thermal shock. The increase in VSWR is most noticeable around the reject frequency in the 4000 to 5000 MC range. The X-ray photograph of this cable after 25 cycles of thermal shock shows that the inner conductor moved further off center. A visual inspection of the inside of the cable at the bend verified this. The dielectric section was compressed a little more and there were more radial cracks. The inner conductor was still held firmly in place and the cable was still operational.

The dielectric spacer seems to be the only border-line part in the cable assembly. Thecrush resistance of the notched dielectric section at 350°C is not quite adequate at the bends where the forces on the section are the greatest.

It should be pointed out that the cable assembly was very successful in the following areas:

a) The metallic seals held pressure (leakage rate within that specified).
b) The gas barriers (glass-to-metal seal) were not damaged.
c) The seam welded outer conductor held pressure.
d) The inner and outer conductors were not damaged.

e) The anchor insulators did a very good job of anchoring the inner conductor.
f) The inner connectors gave no problem, and the insertion pressure had not changed noticeably.
g) The connector hardware was removed with conventional tools and the flanges separated with little effort.

4. Vibration

Two transmission line assemblies were mounted as shown in Figure 145 (a layout of the expansion bend is shown in Figure 144).

Each test specimen was subjected to vibration of 10-70 CPS at 0.06 double amplitude and 70-300 CPS at 15g. The time of one complete 10-300-10 CPS cycle was 30 minutes. Nine such cycles were accomplished on each unit in a direction perpendicular to the cable axis and nine parallel to the cable axis. The fixturing is shown in Figure 29.

Visual inspection at the conclusion of the test revealed no evidence of mechanical damage, distortion or deterioration. Gauge pressure at the conclusion of the test was 25.0 psig and 28.3 psig from an initial 30 psig.

The tests were conducted at Webcor Inc., Government Division, Chicago, Illinois.

The following VSWR measurements and X-rays were taken:

Cable No. 1:

a) VSWR before vibration test (Figure 76)
b) VSWR after vibration test (Figure 78)
c) X-ray before vibration test (Figure 96)
d) X-ray after vibration test (Figure 97)

Cable No. 2:

a) VSWR before vibration test (Figure 77)
b) VSWR after vibration test (Figure 79)
c) X-ray before vibration test (Figure 96)
d) X-ray after vibration test (Figure 97)

DISCUSSION OF TEST RESULTS

The average increase in the VSWR peaks for both cables is between 1.05 to 1.1 (Figures 76-79). This increase in VSWR is actually very small considering the mechanical abuse the cables were subjected to for nine hours.

The X-ray photographs (Figures 96 and 97) revealed the following:
a) Inner conductor concentric.
b) No damage to inner or outer conductor.
c) No damage to connector parts.

The cables were cut open and an internal inspection showed the following:

a) No damage to the dielectric section.
b) No damage to the inner or outer conductors.
d) No metallic particles or dust.

The metallic seals held pressure and did not damage the contact surfaces, the hardware did not loosen, and the cable clamps (lines with glass-filled Teflon insert) did not damage the cable or break.

Earlier vibration tests resulted in the following changes:
a) The rear end of the connector had to be modified to take on an outer conductor stiffener. This stiffener screws over the annealed section of outer conductor and is anchored to the connector. The outer conductor becomes annealed when it is silver soldered to the connector. The stiffener is required for handling and vibration.
b) The clamp spacing was changed from 20 inches to 12-1/2 inches to eliminate the severe low frequency resonances. A clamp is required for every 12-1/2 inches of cable (not including connector), and one should be located on each side and in the middle of the expansion bend as shown in Figure 145.

The expansion bend for cable "B" should be approximately as shown in Figure 144.

c) A non-abrasive insert had to be used with the type 321 S.S. clamp to prevent wear of the copper outer conductor.

A Teflon (TFE), glass filled Teflon, and quartz-filled Teflon insert were tested on a section of cable at 350°C, Figure 28. The Teflon insert distorted, whereas the other two held their shape. The glass filled Teflon is much easier to machine and less abrasive. Therefore, the glass filled Teflon insert was selected.

5. Dielectric Strength and Corona

A cable assembly, 10 feet long, was connected in the test setup shown in Figure 141. The following tests were conducted:
a) Dielectric strength versus pressure using dry air from 0 to 90 psig (Figure 80).
b) Dielectric strength versus pressure using nitrogen from 0 to 30 psig (Figure 81).
c) Dielectric strength versus pressure using Freon-116 from 0 to 45 psig (Figures 80 and 81).

For comparison purposes, dielectric strength tests were run on a 10 foot cable assembly with gas barriers using various inert gases. The following gases were tested:

a) Nitrogen
b) Freon-14
c) Freon-14/Freon-116 (86/14 vol.)
d) Freon-116

C. Cable For -100 to 825°C.

1. Insulation Resistance, Capacitance, Velocity, Characteristic Impedance, and Attenuation measurements versus temperature and time were conducted on one 50 foot length of cable with connectors as shown in Figure 134. The test equipment setups are shown in Figures 135-138, and the measurements are recorded in Tables 7 and 8.

Curves of attenuation versus frequency are given for the following conditions:

a) Attenuation vs frequency @ room Temp. (Figure 100)
b) Attenuation vs frequency @ 200°C (Figure 101)
c) Attenuation vs frequency @ 400°C (Figure 102)
d) Attenuation vs frequency @ 600°C (Figure 103)
e) Attenuation vs frequency after 14 Hrs. @ 825°C(Figure 104)
f) Attenuation vs frequency after 94.5 Hrs. @ 825°C(Fig. 105)
g) Attenuation vs frequency after 121 Hrs. @ 825°C(Fig. 106)
h) Attenuation vs frequency after 185 Hrs. @ 825°C(Fig. 107)
i) Attenuation vs frequency @ room temp. after 200 Hrs. @ 825°C (Figure 108)
j) Attenuation vs frequency @ room temperature (Figure 108a)

(Final prototype cable - Attenuation measurements conducted at room temperature only)

DISCUSSION OF TEST RESULTS

The above measurements were conducted on next to the last cable fabricated. The only change made in the final prototype cable was to increase the OD and wall thickness of the inner conductor. The change was made to lower the characteristic impedance and to strengthen the inner conductor.

The following is a comparison of the room temperature measurements taken on the two cables:

Cable	Capacitance MMF/ft	Velocity Percent	Z_0 Ohms
Experimental cable	21.58	89.4	52.6
Final Prototype cable	22.3	89	51.2

Insulation Resistance: The insulation resistance decreased with temperature as would be expected. The higher the temperature, the more conductive insulators become. The initial and final values of insulation resistance at room temperature were reasonably close.

On the final prototype cable, the initial insulation resistance measured 5 tera ohms which is considerably higher than the 30 giga ohms measured on the experimental cable. It was interesting that the cable with the higher insulation resistance did not

TABLE VII

Measurements On Cable "A"
Prototype Cable (50')

Stabilized Temperature Levels	Insulation Resistance Megohms/50' (TP 4.5.4) 600 Volts	Capacitance MMF/ft (TP 4.5.7)	Velocity Percent (TP 4.5.8)	ZO Ohms (3)	Attenuation db/100' TP 4.5.10
Room Temp. @ 20°C	30K	21.58	89.4	52.6	400 MC - 2.33 1000 MC - 4.14 2000 MC - 6.45 3000 MC - 8.62 4000 MC - 11.35 5000 MC - 14.4
Furnace @ 200°C	2.6K				400 MC - 2.34 1000 MC - 4.08 2000 MC - 6.9 3000 MC - 8.64 4000 MC - 9.14 5000 MC - 12.74
Furnace @ 400°C	1.6				400 MC - 3.1 1000 MC - 5.14 2000 MC - 7.9 3000 MC - 10.08 4000 MC - 10.46 5000 MC - 15.86
Furnace @ 600°C	.06				400 MC - 4.54 1000 MC - 7.46 2000 MC - 10.16 3000 MC - 10.46 4000 MC - 15.6 5000 MC - 20.4
Furnace @ 825°C	.0037		88.8	55.5	400 MC - 8.3 1000 MC - 12.0 2000 MC - 17.2 3000 MC - 22.1 4000 MC - 26.6 5000 MC - 29.2
Room Temp. After 200 Hrs. @ 825°C	25K	21.1	89.5	53.8	400 MC - 2.3 1000 MC - 3.8 2000 MC - 6.1 3000 MC - 9.26 4000 MC - 10.96 5000 MC - 14.36

TABLE VIII

Measurements On Cable "A"
Prototype Cable (50')

Hours @ 825°C	Insulation Resistance Megohms/50' (TP 4.5.4) 600 Volts	Capacitance MMF/ft (Optional)	Velocity Percent (Optional)	Z0 Ohms (3)	Attenuation db/100' (TP 4.5.10)
14	.0037				400 MC - 8.3 1000 MC - 12.0 2000 MC - 17.2 3000 MC - 22.1 4000 MC - 26.6 5000 MC - 29.2
94.5	.0043		88.8	55.5 (1)	400 MC - 8.3 1000 MC - 12.0 2000 MC - 17.2 3000 MC - 22.1 4000 MC - 26.6 5000 MC - 29.2
121	.0044		88.8	55.2 (1)	400 MC - 9.4 1000 MC - 12.5 2000 MC - 17.8 3000 MC - 23.14 4000 MC - 27.74 5000 MC - 33.2
185	.0080		88.8	55 (1)	400 MC - 10 1000 MC - 13.35 2000 MC - 19.3 3000 MC - 24.3 4000 MC - 29.4 5000 MC - 35.0
Ambient After 200 Hrs. @ 825°C	25K	21.1	89.5	53.8 (2)	400 MC - 2.3 1000 MC - 3.8 2000 MC - 6.1 3000 MC - 9.26 4000 MC - 10.96 5000 MC - 14.36

NOTES:
Z0 measured by means of an RF bridge (open and short circuit resistance of quarter-wave section)
Z0 calculated from capacitance and velocity measurements.
On the final prototype cable, the inner conductor OD was increased from .155 to .160 and the measured characteristic impedance was 51.2 ohms.

have the lowest dielectric loss. This is discussed further under "Attenuation".

The above is just mentioned for information. The lower initial insulation did not cause any problems - in fact, the attenuation' readings were considered low if anything.

Attenuation

The attenuation measurements shown in Figures 100-108 are well within the requirements. The attenuation curve in Figure 8a (Final prototype cable) shows a small increase in the dielectric loss in the 3000 to 5000 MC range. As mentioned above, the insulation resistance was actually higher than the cable with the lower attenuation. There were enough measurements made on the low attenuation cable that we can be reasonably confident it was not measurement error.

It should be pointed out however, that the losses are well within the specifications as shown below:

Freq. MC	ASD Spec. db/100'	Experimental cable db/100'	Prototype Cable db/100'
400	3	2.33	2.4
1000	7	4.14	4.0
3000	18	8.62	9.5
5000		14.4	17.5

It is very important that the Refrasil rope be properly heat treated for low attenuation. In fact, it is recommended that the material be heat treated at 825°C just prior to fabricating the cable. This is in addition to the heat treatment given the material at the fabrication. Since it is almost impossible to make the cable without the Refrasil taking on moisture, the cable should be purged with dry air as soon as possible after cable fabrication. The ends are then sealed and the cable pressurized with dry nitrogen. A good megohmmeter should be used to check for moisture in the dielectric.

2. VSWR and Bend Radius

The VSWR of a 10 foot prototype cable assembly, connected as shown in Figure 139, was measured and X-rays taken for the following conditions:

a) Straight length of cable with connectors (Figures 110,111,& 128)
b) 10" diameter bend (Figures 112, 113, and 129).
c) 6-1/2" diameter bend (Figures 114, 115, and 129)
d) 4-1/2" diameter bend (Figures 115, and 130)
e) 3-1/2" diameter bend (Figures 116, 117, and 130)

The VSWR of the cable assembly (with connectors) is under 1.3 up to 2000 MC and under 1.4 over most of the 2000 to 5000 MC range. The VSWR in the vicinity of the reject frequency (3400 MC) is a little higher as would be expected.

The VSWR curves in the 600 to 3000 MC range look exaggerated because of the expanded VSWR scale. The VSWR scale used for the 3000 to 5000 MC range is more appropriate. Figures 124a-d show actual recordings of the VSWR in the 500 to 3000 MC range.

The VSWR of the two connectors back-to-back is shown in Figure 98. The maximum VSWR is 1.2 when the connectors add up in worst phase. As discussed previously, the connector VSWR could be improved over a smaller frequency range.

It is very possible that the VSWR of the cable itself can be improved. As experience is gained in fabricating the cable, the VSWR will improve. Another area for improvement is the Refrasil rope. It may be possible to hold closer tolerances on the Refrasil rope.

The change in VSWR with bend radius is very small, even for the 3-1/2" diameter bend. (Figures 110-117).

VSWR measurements were not made in the 3000 to 5000 MC range for the 6-1/2" and 4-1/2" diameter bend because there was not enough time. However, this range is covered for the smaller 3-1/2" diameter bend and the change in VSWR is very small.

The inner conductor remained concentric down to and including the 3-1/2" diameter bend (Figures 128-130). The 3-1/2" diameter bend is not a perfect circle because it was partly formed by hand. This is about as small a diameter as the cable will bend on.

The 3/8" cable is rather stiff and springy because it is made from a high strength nickel alloy (Inconel). It will form around small diameter mandrels, but care must be taken to back up the bend while forming so as not to kink the cable. There is usually some spring back, therefore, it may be necessary to bend on a smaller diameter than what is desired. Also, the diameter should be progressively reduced for best results.

3. Thermal Shock

The thermal shock tests conducted on this cable are not complete. There was not enough time to conduct a complete series of tests on the prototype cable.

A thermal shock test on an experimental cable consisted of coiling a length of cable on a 10" diameter and anchoring the inner conductor by squashing the ends and rolling. The cable was subjected to 10 cycles of thermal shock (-65 to 825°C) as described in section IV B.3 above. The purpose of the test being to determine what, if anything, would happen to the inner conductor and Refrasil rope spacer. The cable was X-rayed after 10 cycles and the X-ray revealed a slight wave in the inner conductor at two places. Otherwise, it appeared concentric. The cable was cut open and the Refrasil was in good condition.

A five foot prototype cable assembly was set up as shown in Figure 140. Since this cable does not have a gas barrier, the connectors were sealed with blank flanges. In the haste to run the test, the inner connectors were not mated to firmly fixed receptacles as specified. As a result, after 10 cycles of thermal shock, it was observed that the inner conductor had pushed through and damaged the anchor insulator. This test did not seem to be quite fair because the inner connector is always mated in a system.

The failure was repeated and found to occur when the cable was taken from the 825°C oven after two hours and exposed to room temperature. The outer conductor is thin and as a result cools fast (contracts), whereas, the inner conductor is insulated and remains hot. For a short period of time, the inner conductor exerts a great amount of force on the anchor insulator. Since this is a small cable, the inner conductor and undercut (at the anchor insulator) are small and as a result all this force is exerted on a small area of the Boron Nitride anchor bead.

There was not time to make a new test setup with mating receptacles, etc., so it was decided to run a quick test to see what would happen if the connectors were mated. This was accomplished by bending a five foot cable around and connecting to itself.

At the end of three and five cycles of thermal shock, the connectors were opened and examined, and the VSWR measured. The anchor insulators were not damaged and the VSWR was not much different than 5 foot cable assemblies that were not thermal shocked (Figure 120 can be used for VSWR comparison).

The X-ray (Figure 132) shows some waviness in the inner conductor - not serious enough to do any harm. The connectors and anchor insulators were not damaged.

Although the above tests are not conclusive, they do look promising. The thermal shock test is probably the most severe test this cable has to pass. The conductors are actually red hot when the cable comes out of the oven.

The materials used in this cable are not border-line, they all have adequate strength and life at 825°C.

Further thermal shock tests will have to be conducted on this cable to make certain that the anchor insulator design is adequate for the application it is intended for. If it is not, changes can be made in the anchor insulator design.

4. Vibration

A vibration test was not conducted on the final prototype cable because there was not enough time. However, a complete vibration test was conducted on one of the earlier cables. Unfortunately, the VSWR was not measured before and after the vibration test. At the time, the main concern was whether or not the cable and connectors would withstand the specified vibration. The test was a success and the cable was X-rayed (Figure 133). The inner

conductor showed a little wavy at one end. It is possible that this was caused by the pressure of the Refrasil spacer at the bend.

The cable was cut open in a number of places and there was no indication that the Refrasil had been damaged. In fact the cable was in excellent condition.

After observing the X-ray, it was decided that possibly the inner conductor could use a little heavier wall. Consequently, on the final prototype cable, the thickness of the Inconel wall was increased from .012" to .019", making the overall wall thickness .027".

The final prototype cable was not subjected to the vibration test. All that can be said at this time is that with the expansion bend shown in Figure 143, and the test setup shown in Figure 145, the experimental cable withstood the 4-1/2 hours of vibration in each plane. The connectors used on the experimental cable were the same design as used on the prototype cable.

There is one problem connected with vibrating this cable, and that has to do with the clamps. Since metal clamps cannot be clamped right over the metal outer conductor, some type of liner has to be used. At the time, a Teflon liner was used because it was the only thing available. Obviously this could not be used at 825°C. Since then, a number of other liners and clamps have been investigated. The most promising one is a dense mesh liner fabricated from metallic fibers (type 321 S.S. or Inconel). The liner has to be impregnated with a dry high temperature lubricant. More testing will be required to determine the best material, density, and configuration.

If the cable is properly fabricated, and the expansion bend and cable clamping specified is used, this cable should have no trouble passing the vibration test. Vibration cable assemblies are shown in Figure 35.

5. Dielectric Strength and Corona

A cable assembly, 10 feet long, was connected in the test setup shown in Figure 141. The following tests were conducted:

a) Dielectric strength versus pressure using nitrogen from 0 to 60 psig (Figure 109).
b) Dielectric strength versus pressure using Freon-14 from 0 to 35 psig (Figure 109).
c) Dielectric strength versus pressure using Freon-14/Freon-116 (Mixture - 86/14 vol.) from 0 to 15 psig (Ran out of gas - test discontinued).

Freon-14 is the best gas for this application since it is the most stable of all florocarbon gases. The mixture could be

used for higher dielectric strength, but its boiling point is close to -100°C.

Neither one of these gases have been fully evaluated for reasons discussed in section II. F. 2. However, the Freon-14 looks very promising..

The Freon-14 falls short of meeting the 5000 volts RMS requirement at 6 psig. This value of dielectric strength is not very realistic when compared with 6000 volts RMS for the 7/8" cable.

The dielectric strength of this cable, pressurized to 6 psig with Freon-14 is 4000 volts RMS.

Here again, it was not possible to run a curve of corona extinction voltage versus pressure because the corona did not appear until breakdown.

SECTION VI

CONCLUSIONS

Two sizes of High Temperature Transmission Lines have been demonstrated and shown to be feasible. Both cables meet the requirements of low loss, high power, high temperature, and flexibility.

Cable For -65 to 350°C

This cable meets most of the requirements of R & D Exhibit WCLK 59-24 with the possible exception of the maximum temperature. The temperature and thermal shock tests showed only limited capabilities at 350°C for long term applications. This is because the quartz-filled Teflon helix does not appear to have adequate strength at 350°C to prevent the inner conductor from moving off center at the bends where the crushing force is quite large.

The results of the thermal shock tests showed that there was little degradation in VSWR after 10 cycles and the X-ray revealed that the inner conductor had moved just slightly off center. However, after 25 cycles of thermal shock, the increase in VSWR and the inner conductor eccentricity were more pronounced. At no time did the cable fail and after 25 cycles of thermal shock it was still operational, as it was after 200 hours at 350°C.

It is doubtful that much would be gained from further efforts to improve the physical properties of quartz-filled Teflon at 350°C. If the mixture were changed to increase its crush resistance, it would probably be less flexible. If the section were less flexible, it would require more tension to wrap it around the inner conductor. Filled Teflon, as well as Teflon, has very little tensile strength above 327°C. With the present design, which uses very little tension, there is still some cracking at 350°C.

Further improvement in the dielectric loss of the quartz-filled Teflon section is possible. Future experimental efforts should be directed along this line. The use of a volatile lubricant for extruding the section and special preparation and handling of the quartz filler will certainly help.

The quartz-filled Teflon insulated cable is recommended for long cable life at temperatures up to 300°C and for short life at 350°C. The cable will perform very well for at least 10 cycles of thermal shock. Heat tests conducted on the cable show that the quartz-filled Teflon starts to lose its superior physical properties around 327°C (the transition or melting temperature of Teflon). However, of all the filled Teflons tested, the quartz-filled had the best physical properties for cable application above 327°C.

If increased cable life is desirable at temperatures above 300°C, it may be better to develop a Refrasil core for this cable. A short length of Refrasil rope was made for this cable size and it looks promising. It is possible that such a cable could be rated higher than 350°C. The maximum temperature would depend on thermal shock and pressure-temperature test results on the copper cable.

The fabrication of this cable is such that the quartz-filled Teflon section can very easily be replaced with Teflon (TFE). The Teflon section can be used for long cable life up to 250°C and short cable life up to 300°C. The Teflon section has the advantage of lower dielectric loss. The loss of quartz-filled Teflon is approximately four times that of Teflon (TFE). Even if the power factor of quartz-filled Teflon is reduced to 0.0005, it still has three times the loss factor.

It is possible, at the higher frequencies, for a Teflon (TFE) cable to have a higher average power rating than a cable using quartz-filled Teflon because of the dielectric loss. The dielectric loss or heat generated is directly proportional to frequency and average power. Since the Teflon (TFE) cable has approximately one-fourth the dielectric loss, it will generate less heat and run cooler (See Appendix A).

At the lower frequencies, the quartz-filled cable will operate at higher average powers; at low power levels, it will operate at higher ambient temperatures than Teflon (TFE).

The dielectric used will depend on the average power, frequency and maximum ambient temperature. There is no advantage in using quartz-filled Teflon if the maximum temperature is within that recommended for Teflon (TFE). The disadvantage, of course, is increased attenuation. This discussion is not meant to discourage the use of quartz-filled Teflon, but rather to make sure its advantages and disadvantages are understood and that it is used only in applications where it has a definite advantage.

Any future program which involves conducting high average power tests to determine life-index or power rating should include a Teflon (TFE) insulated cable. The construction would be the same as the quartz-filled Teflon insulated cable proposed in this report.

The manufacturing problems connected with fabricating these cables have been solved. Any future effort will be directed toward increasing the maximum lengths possible. This will result in better electrical performance and reduced cost. This cable assembly, including connectors and gas barrier, is ready for production.

Cable For -100 to 825°C.

This cable also meets most of the requirements of R & D Exhibit WCLK 53-24 with the possible exception of the thermal shock requirement. The thermal shock tests were not completed and the results are not conclusive.

The materials used in this cable are not border-line, they all have adequate strength and life at 825°C. In fact, it is possible that the cable could operate up to the melting point of the silver which is 960°C.

The electrical, mechanical, and thermal properties of this cable in the -100 to 825°C temperature range are very good. The only problem area is thermal shock. In going from 825°C to room temperature, the outer conductor cools and shrinks much faster than the insulated inner conductor. The differential contraction resulted in excessive forces on the anchor insulator and consequently, the inner conductor pushed through and damaged the Boron Nitride insulator. As mentioned in the text, the inner conductor was not mated to a firmly fixed receptacle as specified, so it is questionable whether or not the test was a failure. When the test was repeated with the cable formed in a circle and the ends connected, the anchor insulators were not damaged.

It is unfortunate that there was not enough time to resolve this problem, because the solution may be as simple as changing the diameter of the inner conductor adjacent to the bead to increase the surface area and consequently decrease the force per unit area at the I.D. of the bead. If necessary, the thickness of the bead could also be increased. The connector or receptacle to which it is mated, can also be expected to relieve some of the force from the anchor insulator.

The VSWR will improve as experience is gained in the fabrication of the cable. Considerable progress has been made in working with the Refrasil rope and still more is possible.

It is proposed that future experimental efforts be directed toward refining and improving the fabrication techniques in an effort to improve the electrical performance and the manufacturing efficiency.

Since it was not possible to complete all of the environmental tests, it is recommended that such tests be part of any future program.

Also, a separate gas barrier is required for this cable. The connectors use metallic type seals for through-type pressurization. A design similar to the 350°C gas barrier is recommended. (See Figure 151).

This cable might also be considered for short life at temperatures above 960°C (the melting point of silver) if gold clad Inconel conductors are used. The clad metal fabricators have indicated that it is feasible, but it would require development.

APPENDIX A

AVERAGE POWER RATING

Average power rating is based on a safe inner conductor temperature rise. The maximum temperature is usually limited to the type of dielectric spacer used.

The total inner conductor temperature is the sum of the increase in temperature due to the cable losses plus the ambient. The cable losses consist of the inner and outer conductor copper loss which is proportional to the square root of the frequency and the dielectric loss which increases directly with frequency. The power loss and consequently the heat generated, increases with frequency and average power.

For low average power (as in receiver applications), the only effect of increase dielectric loss is increased attenuation. The cable can be used in ambients up to the rating of the materials. For example, if quartz-filled teflon is rated for long life at 300°C, then it can be used in ambients up to 300°C.

For high average power cables, we have to be concerned with the heat generated in the conductors and the dielectric spacer. If the dielectric loss is high, the heat generated will be high, especially at the higher frequencies. In this case the total temperature of the material is the sum of the temperature resulting from the heat generated plus the ambient. This total temperature has to be within the rating of the material.

It is then possible for a low loss cable, with a lower temperature rating, to operate at equal or higher average power than a cable with higher losses and a higher temperature rating.

The curves shown in Figures 150a and 150b indicate that the teflon (TFE) insulated cable has a higher average power rating than the quartz-filled teflon cable for a given inner conductor temperature rise. The reason we are making a point of this is because, when it is at all possible, the teflon (TFE) section should be used since it has the lower loss, and nothing would be gained by going to the quartz-filled teflon insulated cable.

For example, if the ambient temperature is 300°C and the average power level is low, the quartz-filled teflon cable would be preferred for long life. This is one extreme case.

However, for an average power requirement (for example 3 KW at 3000 MC), the two cables would be rated as follows: (Refer to Figures 150a and 150b)

Teflon (TFE)	Quartz-Filled Teflon
150°C (Rise)	261°C (Rise)
100°C (Ambient)	39°C (Ambient)
250°C Total	300°C Total

The Teflon (TFE) cable will handle the same average power and work at a higher ambient and still operate within the 250°C maximum temperature for long life.

The power rating curves in Figures 150a and 150b are per 100°C inner conductor temperature rise. The maximum average power rating can be calculated as follows:

$$P' = P \times \left(\frac{250^\circ C - \text{Ambient}}{100^\circ C}\right) \qquad \text{(Teflon - TFE)}$$

$$P' = P \times \left(\frac{300^\circ C - \text{Ambient}}{100^\circ C}\right) \qquad \text{(Quartz-Filled Teflon)}$$

Where (P) is the average power rating per 100°C inner conductor temperature rise - taken from the curves.

BIBLIOGRAPHY

1. E. T. Pfund, Jr., "Cable, R.F. coaxial, Low-loss, High Temperature". United Electrodynamics. AF33(616)5189.

   Scientific Reports No. 1 - July 10, 1957
   Scientific Reports No. 2 - October 10, 1957
   Scientific Reports No. 3 - January 10, 1958
   Scientific Reports No. 4 - April 10, 1958
   Scientific Reports No. 5 - July 10, 1958
   Scientific Reports No. 6 - October 10, 1958
   Scientific Reports No. 7 - January 10, 1959

2. E. T. Pfund, Jr. and Capt. Bard Suverkrop, "Cable, R.F. coaxial, Low-loss, high temperature". United Electrodynamics and Electronic Technology Laboratory. WADC Technical Report 59-211.

3. ARF 2204-10 Report, "Metals for High-Temperature Coaxial Cable", Armour Research Foundation, July 10, 1961.

4. ARF R3501-B28-1 Report, "Metals for High-Temperature coaxial Cable", Armour Research Foundation, March 13, 1962.

5. Research Laboratory Report CRO-701, 'The formulation and trial production of quartz-filled teflon beading for the Andrew Corporation, The Polymer Corporation, Reading Pennsylvania, October 13, 1961.

6. J. V. Malek, research on R.F. coaxial connectors, broadband, high-temperature, radiation resistant, Amphenol Connector Division, Scientific Reports 1-8 on Contract AF33(616)6243.

7. Publication, "Zirconium Copper 992, a high conductivity - temperature resistant copper", David S. Neill, Technical Editor, Bridgeport Brass Company.

8. Donald Peckner, "Three New Copper Alloys with High Conductivity", Materials in Design Engineering, PP18-19; May 1960.

9. Technical Publication, "OFHC Brand Copper", The American Metal Company, Limited.

10. Publication, "Insulation" Director/Encyclopedia Issue, May 1962.

11. Technical Bulletin T-7, "Engineering Properties of Inconel", The International Nickel Company, Inc.

12. Technical Bulletin HTM-300, "High Temperature Metals", Universal-Cyclops Steel Corporation.

13. Publications Handbook C-16, "Amzinc" Zirconium-OFHC copper alloy.

14. Publication C-25, "Anaconda Copper for Electrical Conductors", The American Brass Company.

15. Technical Bulletin T-38, "Inconel-X", The International Nickel Company, Inc.

16. Publication, "Materials Selector Issue, Vol. 54, No. 51", Materials in Design Engineering, Mid-October 1961.

17. Technical Bulletin, Kovar Alloy, The Carborundum Company.

18. Technical Bulletin B-83 (Rev), "Properties of Selected Commercial Glasses", Corning Glass Works, Corning, New York.

19. Publication, "Information on Code 1723 Glass", Corning Glass Works, Corning, New York, December 14, 1959.

20. Bulletin No. B-91, "Vycor Brand Glasses", Corning Glass Works, Corning, New York.

21. Dr. J. K. Davis, "Developments in Glass Technology Aid Electronic Designs", Electronic Equipment Engineering, December 1958.

22. Publication F30,134, "Comparative Properties of Haynes High-Temperature Alloys", Haynes Stellite Company, October 1960.

23. Publication, "Carpenter High Temperature Alloys", The Carpenter Steel Company, Reading, Pennsylvania.

24. Publication, "Properties and Applications of Reinforced Teflon", By Frank M. Chapman, E.I.DuPont de Nemours & Company, (Inc.)

25. Technical Bulletin No. G-10, "Designing with Teflon TFE - Fluorocarbon Resins at High Temperatures".

26. Technical Bulletin CBO, "Boron Nitride", The Carborundum Company.

27. Information Bulletin, No. X-60b "Teflon - Use of Inorganic Additives", E.I.DuPont de Nemours & Co. (Inc.)

28. Bulletin No. BR-9, "Fluorosint TFE Resin", The Polymer Corp. of Pennsylvania.

29. Publication, "General Electric Quartz Yarn", General Electric Company, Willoughby Quartz Plant, Willoughby, Ohio.

30. Products Bulletin No. PB 1-2, "HITCO "Refrasil" Materials for High Temperature Applications", H.I.Thompson Fiber Glass Co.

31. Products Bulletin No. PB 1-3, "Refrasil Yarn and Cordage, H. I. Thompson Fiber Glass Company.

32. M/DE Manual No. 172, "Introduction to High Temperature Metals", Materials in Design Engineering, June 1960.

33. Product Bulletin, "Metallic Static Face Seals", Haskel Seals, Division of Haskel Engineering & Supply Company.

APPENDIX B

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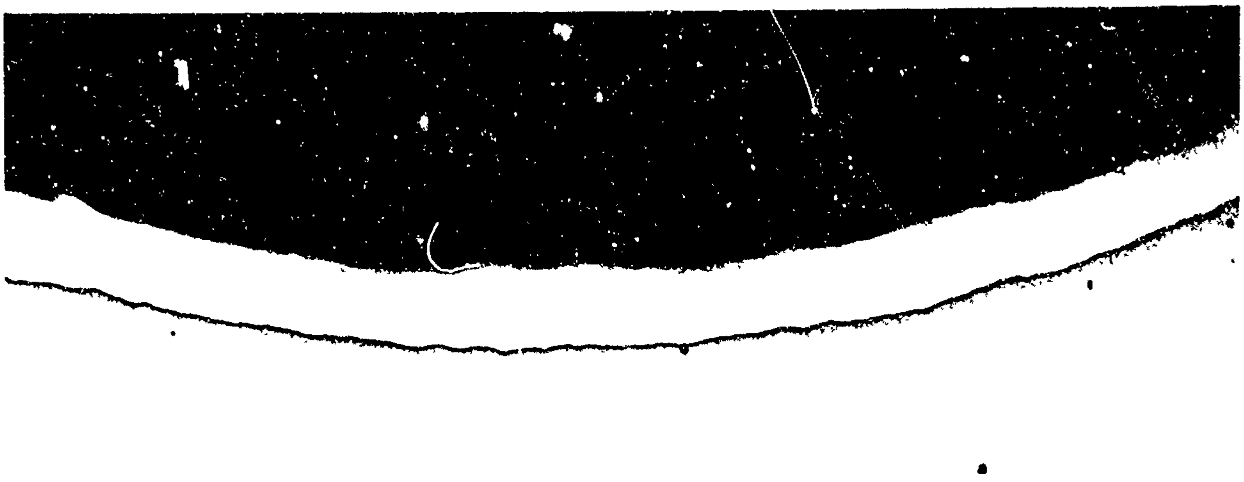

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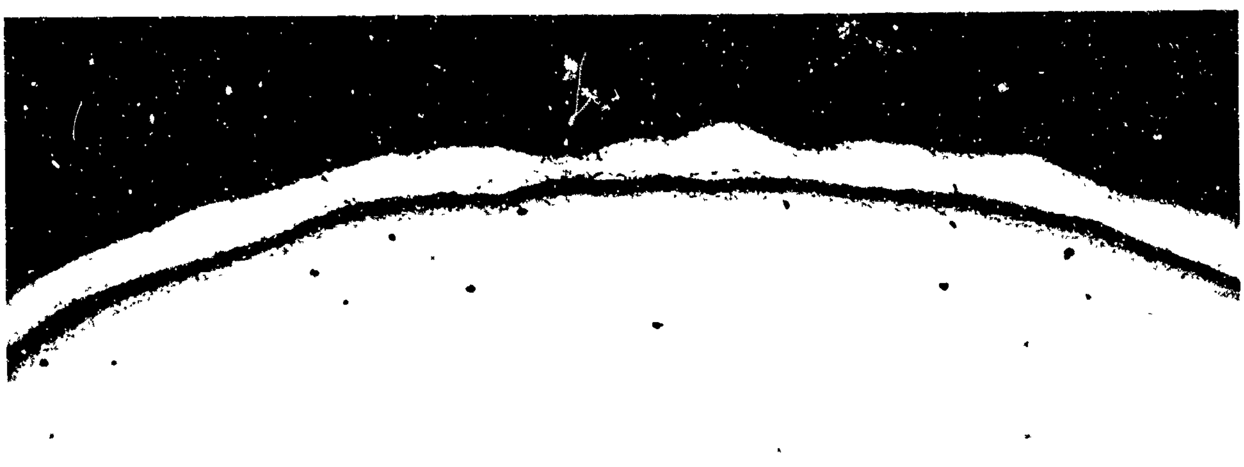

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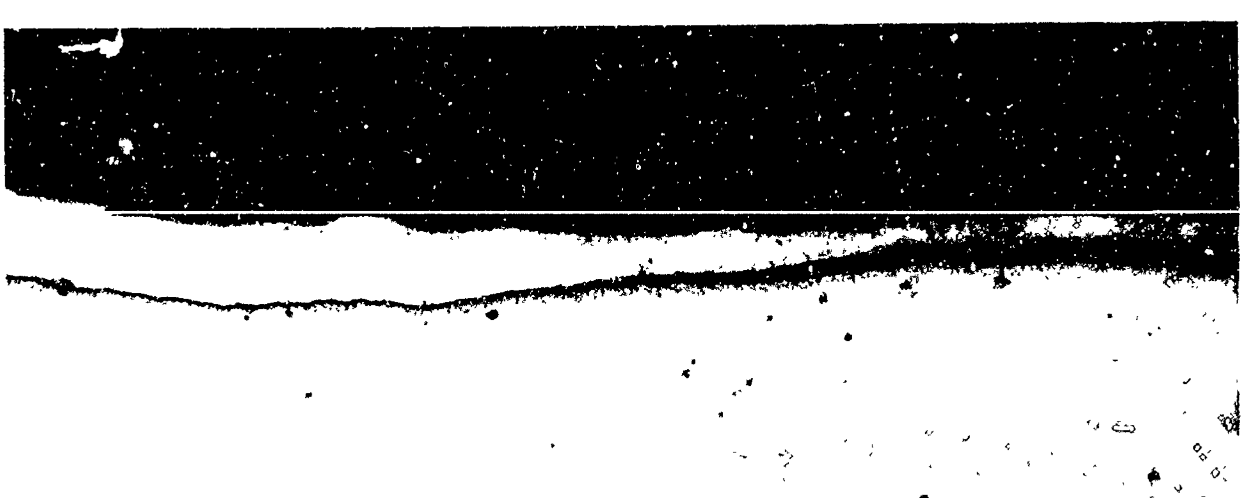

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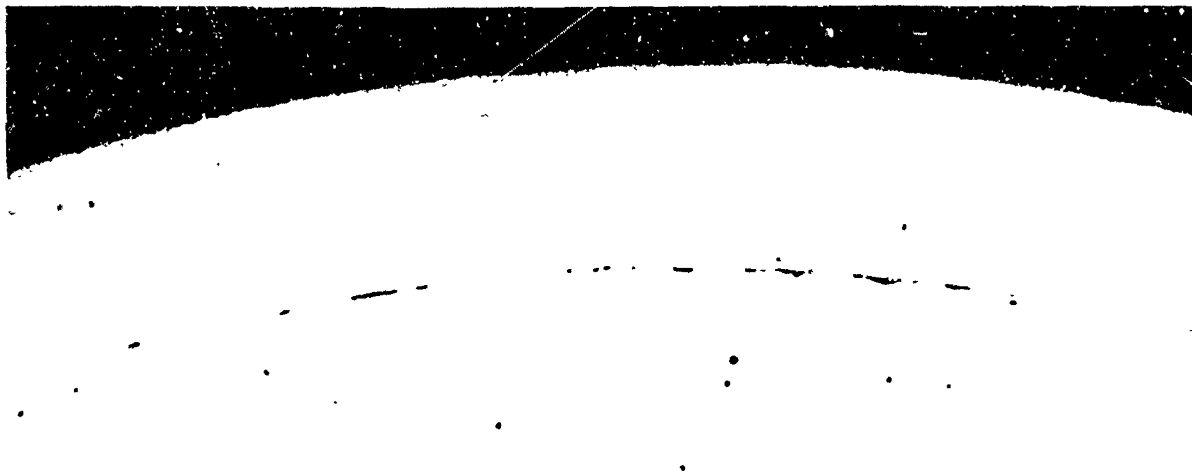
Fig. 1 - Typical sections of as-received 1/2-in. corrugated tubing made of 0.018-in. Inconel clad internally with 0.002-in. of silver. X150.



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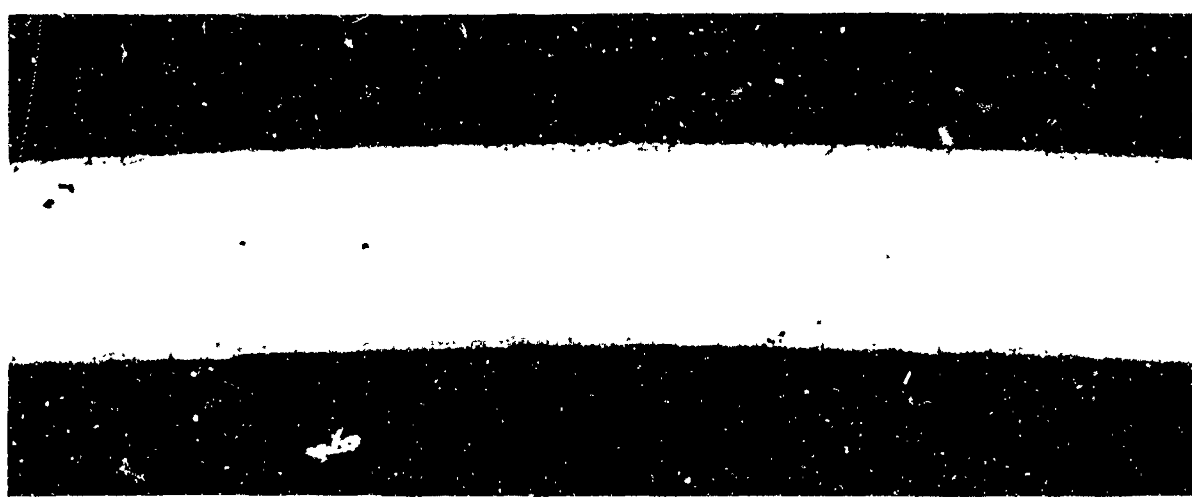

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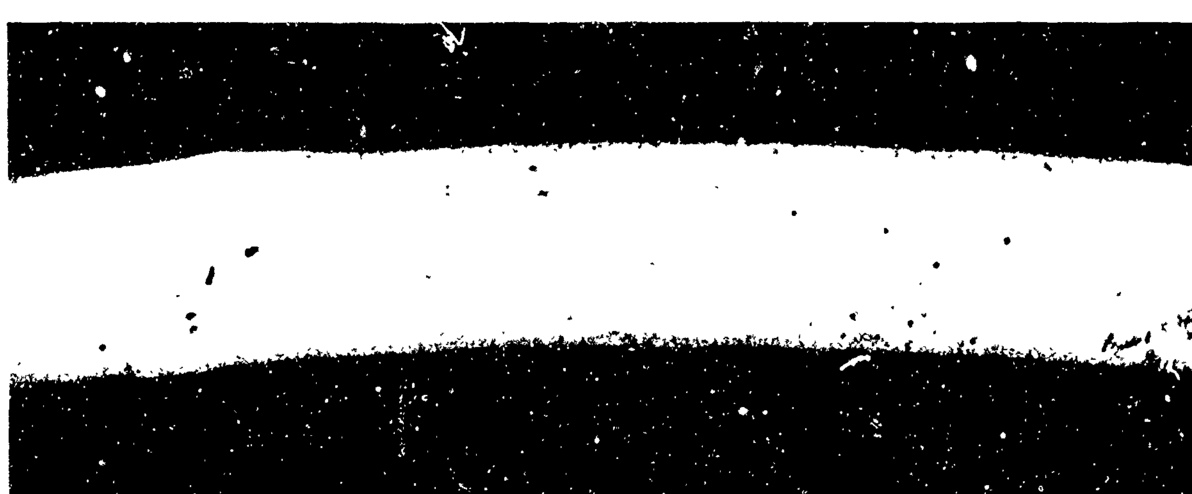
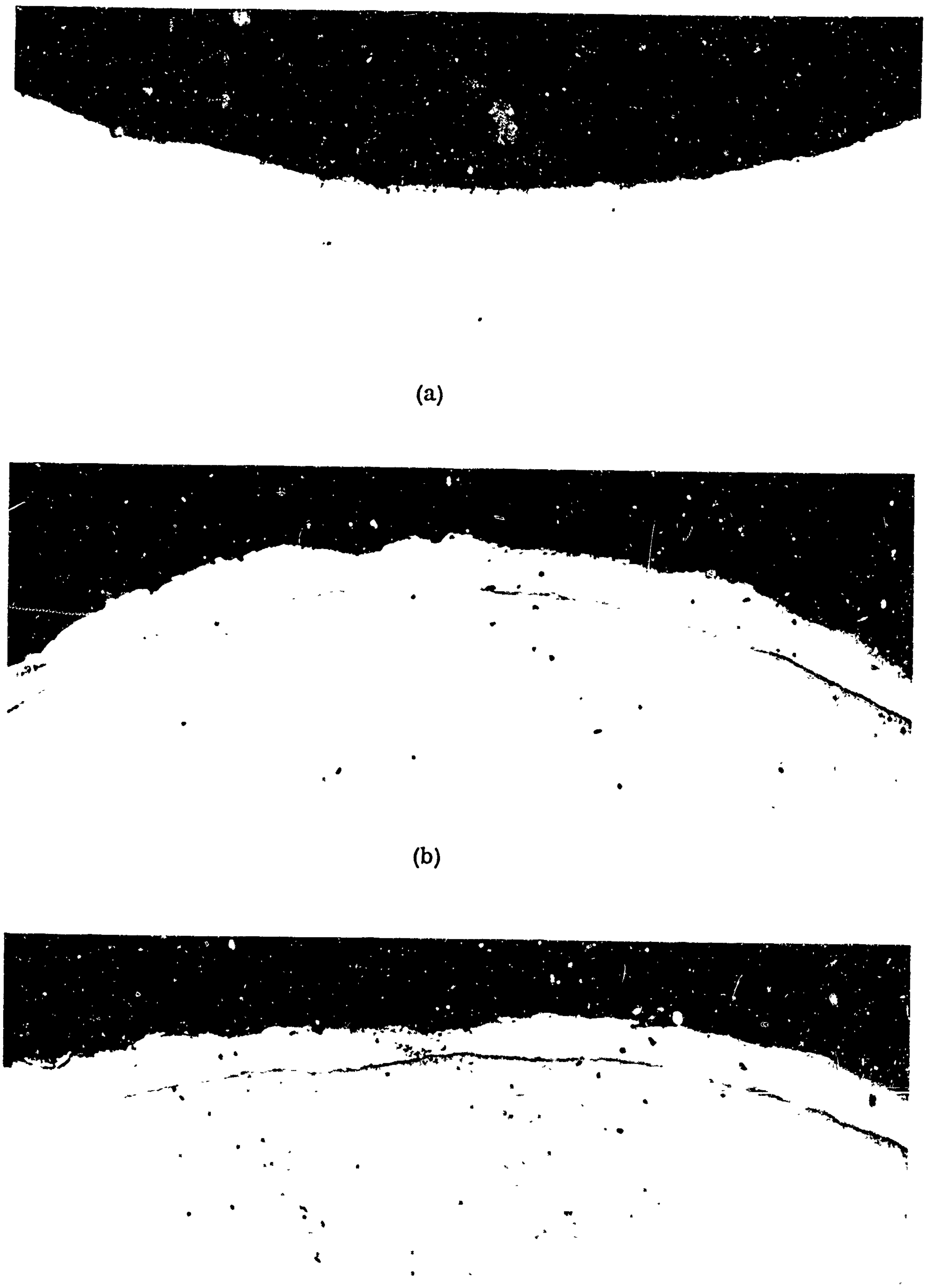


(c)

Fig. 2 - Section of as-received 0.155-in. tubing made of 0.012-in. Inconel clad externally with 0.002 in. of silver over 0.006 in. of nickel. X150. (a) Composite intact. (b), (c) Nickel and silver mechanically stripped from the Inconel.



(a)

(b)

(c)

Fig. 3 - Sections of silver-clad Inconel outer conductor after 216 hours at 825° C in nitrogen. X150.

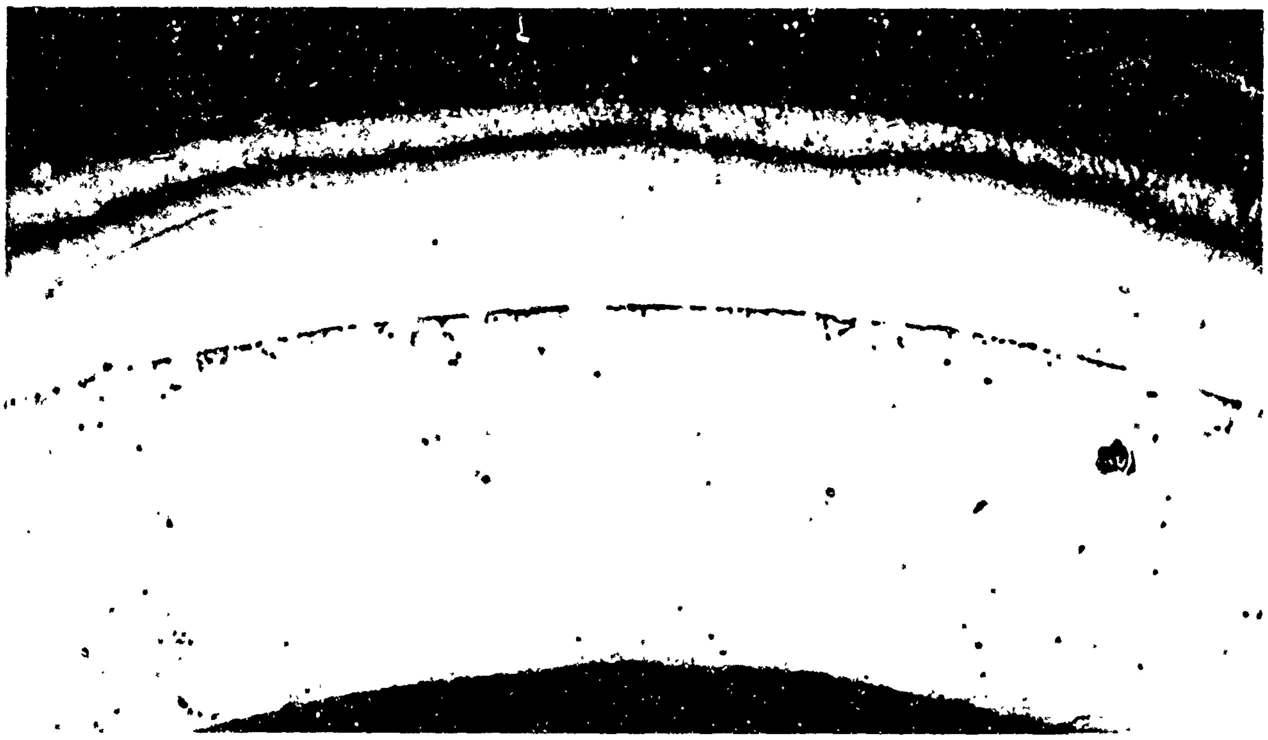
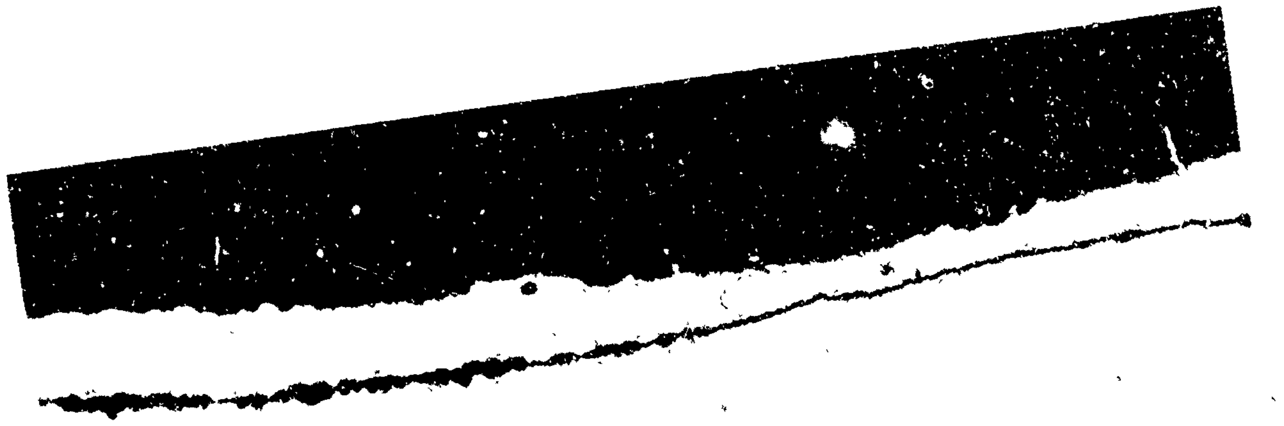


Fig. 4 - Nickel- and silver-clad Inconel inner conductor after 216 hours at 825° C in nitrogen. X150.



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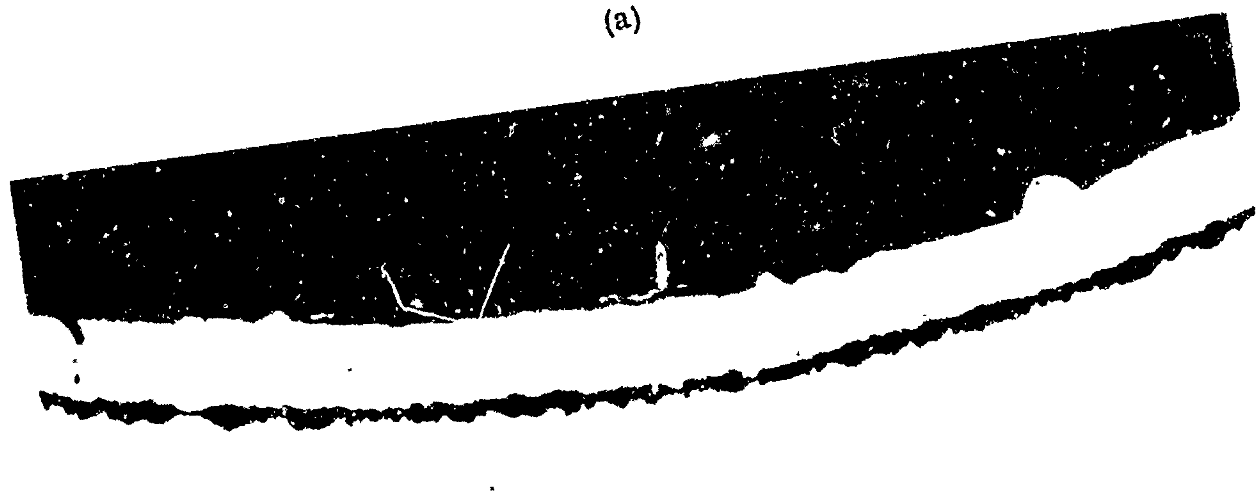

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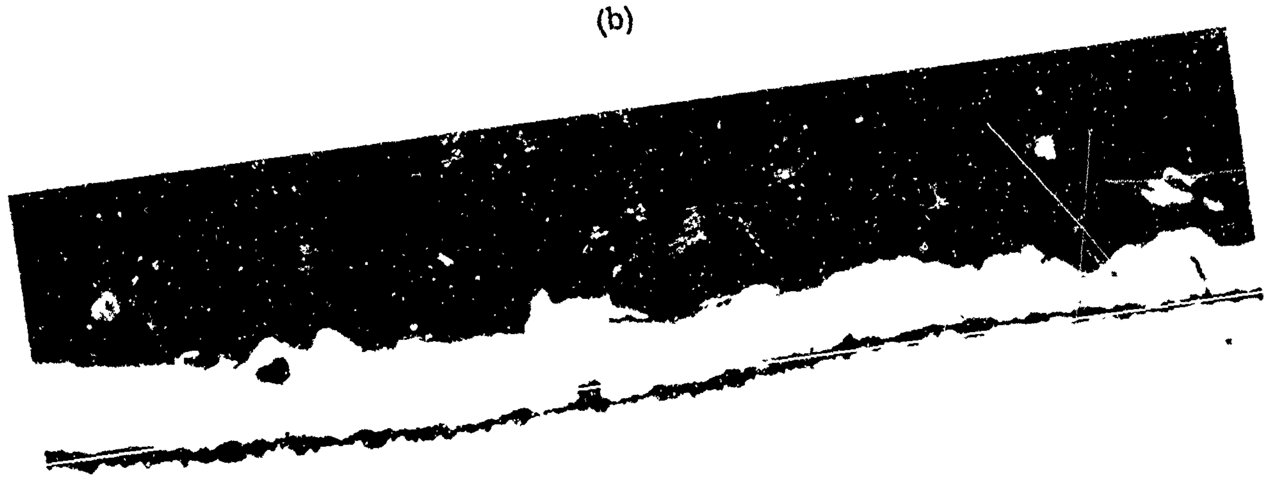


(c)

Fig. 5 - Silver-clad Inconel outer conductor after 216 hours at 825° C in air. X150.

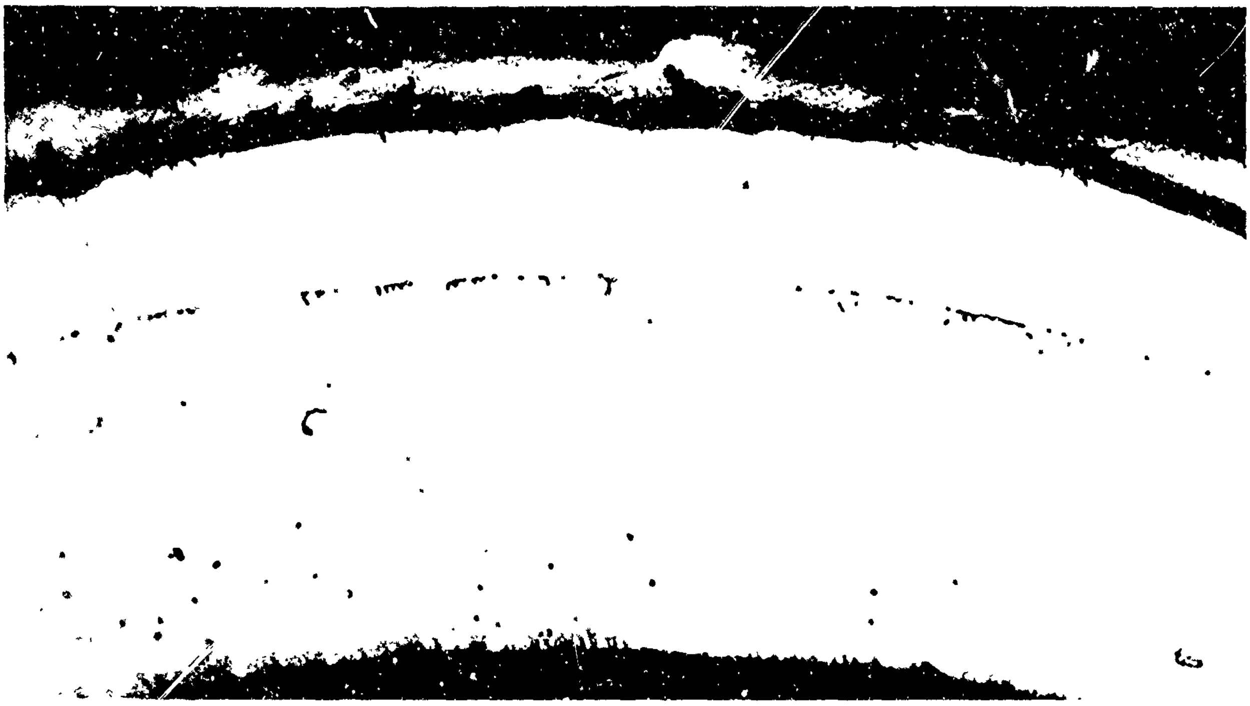


Fig. 6 - Nickel- and silver-clad Inconel inner conductor after 216 hours in air at 825° C. X150.

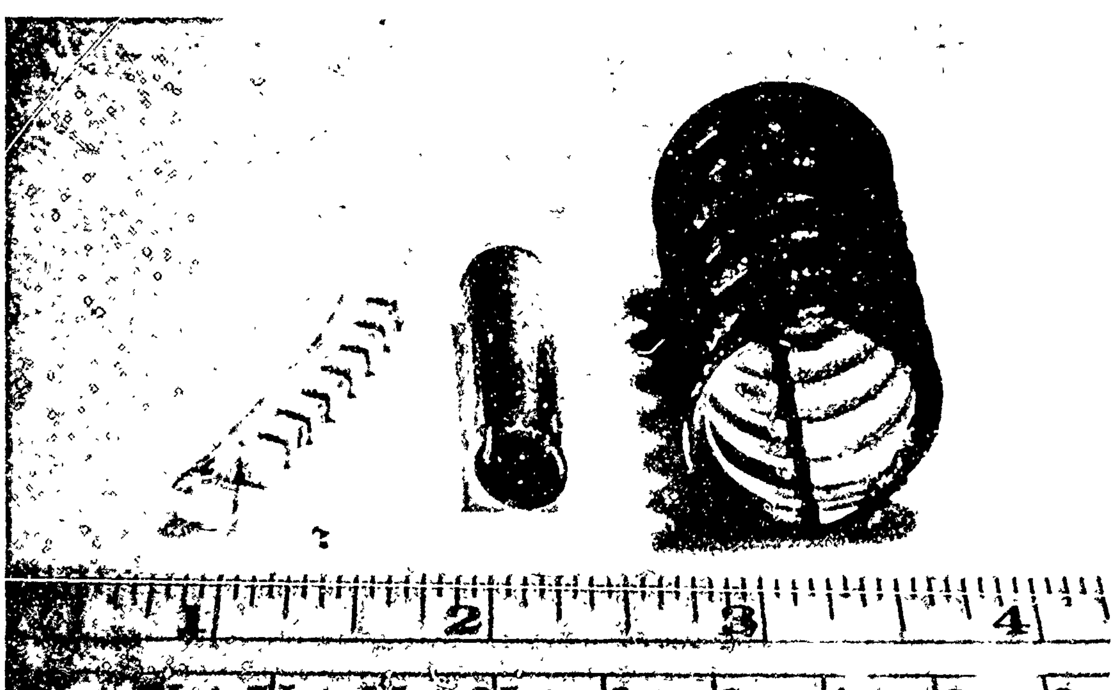


Fig. 7 - Samples of quartz-filled teflon, silver-clad copper inner conductor, and silver-clad copper outer conductor after 200 hours at 350° C in air.

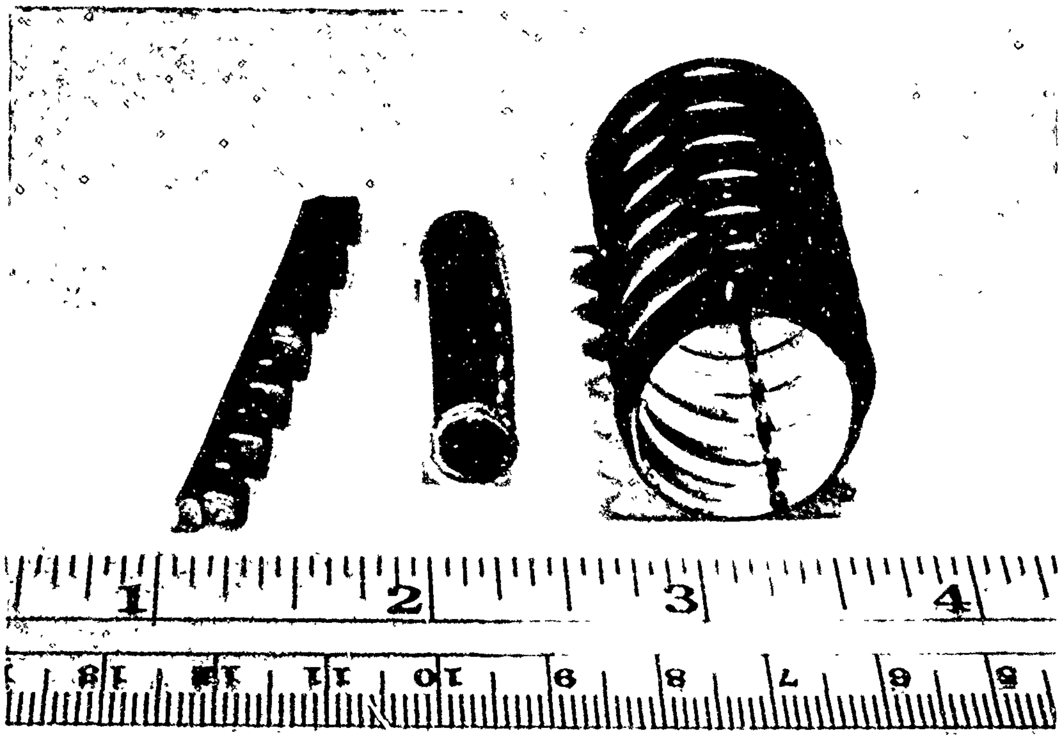
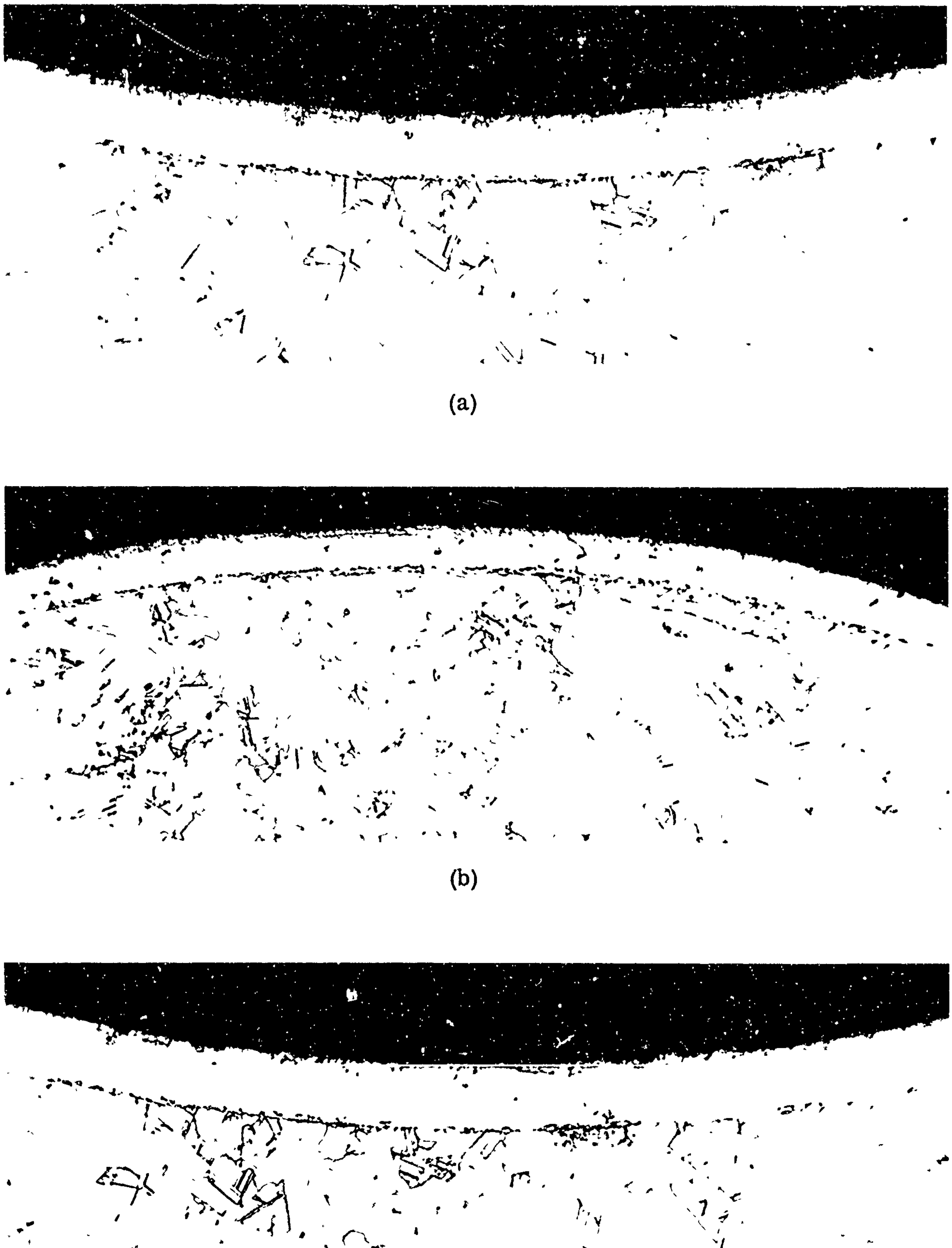


Fig. 8 - Samples of quartz-filled teflon, silver-clad copper inner conductor, and silver-clad copper outer conductor after 200 hours at 350° C in Freon 116.

Fig. 9 - Quartz-filled teflon, silver-plated stainless steel connector, silver-clad copper inner conductor, and silver-clad copper outer conductor after 200 hours at 350° C in nitrogen.



(a)

(b)

(c)

Fig. 10 - Silver-clad OFHC copper outer conductor after 200 hours at 350° C in air. X150.

Fig. 11 - Silver-clad OFHC copper inner conductor after 200 hours at 350° C in air. X150.

(a)

(b)

(c)

Fig. 12 - Silver-clad OFHC oopper outer conductor after 200 hours at 350° C in nitrogen. X150.

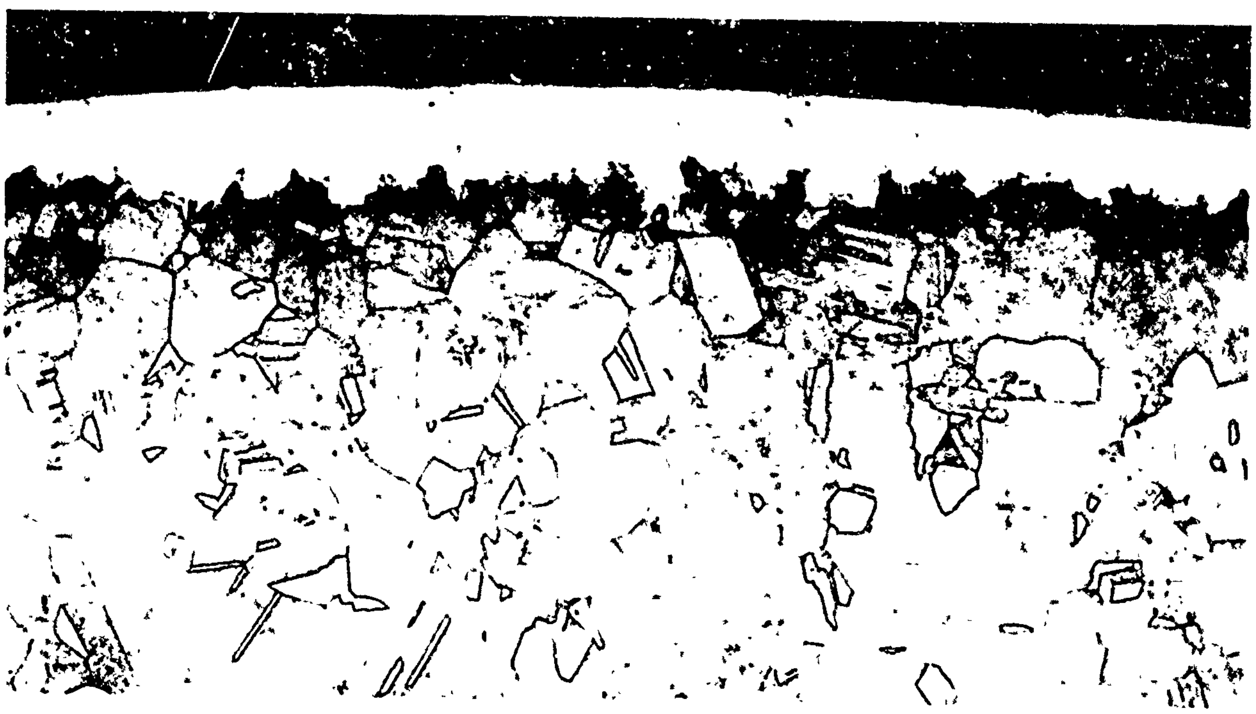
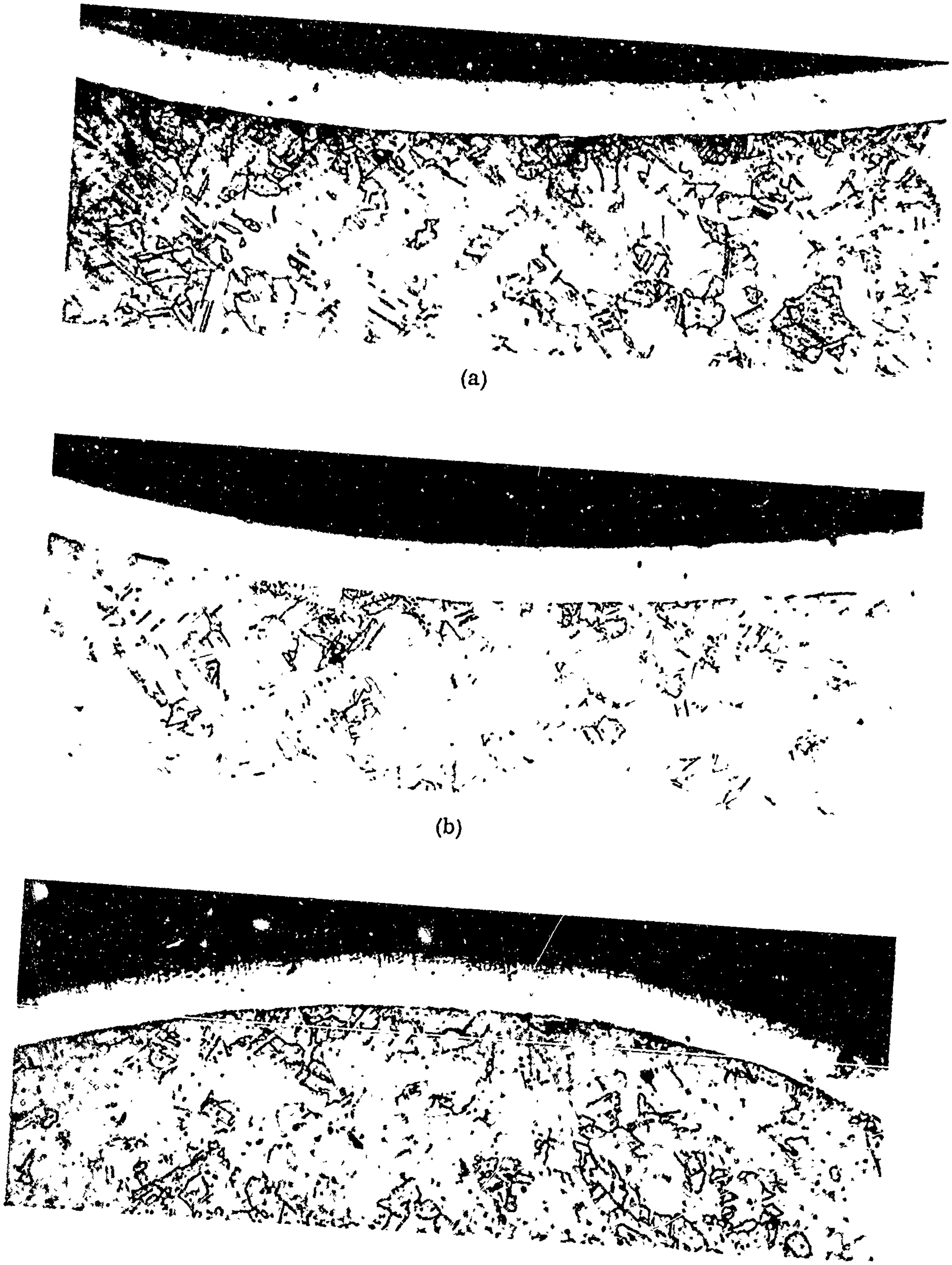


Fig. 13 - Silver-clad OFHC copper inner conductor after 200 hours at 350° C in nitrogen. X150.



(a)

(b)

(c)

Fig. 14 - Silver-clad OFHC copper outer conductor after 200 hours at 350^{o} C in Freon 116. X150.

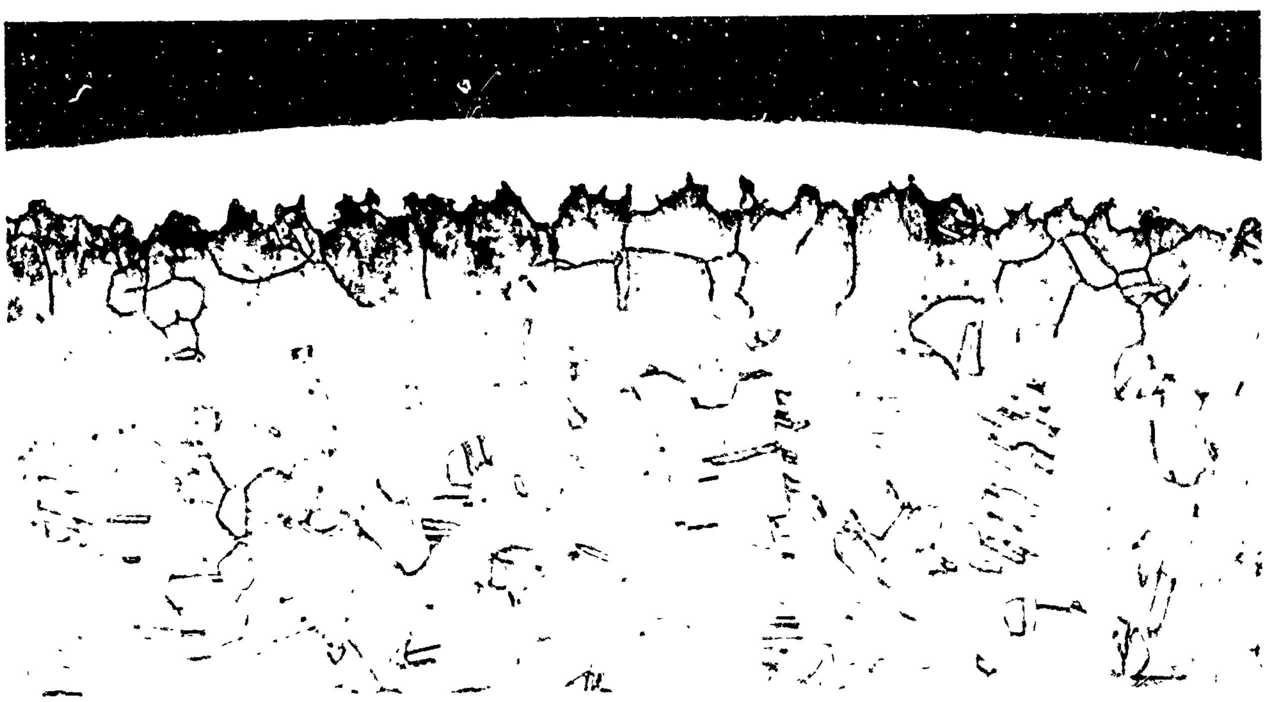


Fig. 15 - Silver-clad OFHC copper inner conductor after 200 hours at 350°C in Freon 116. X150.

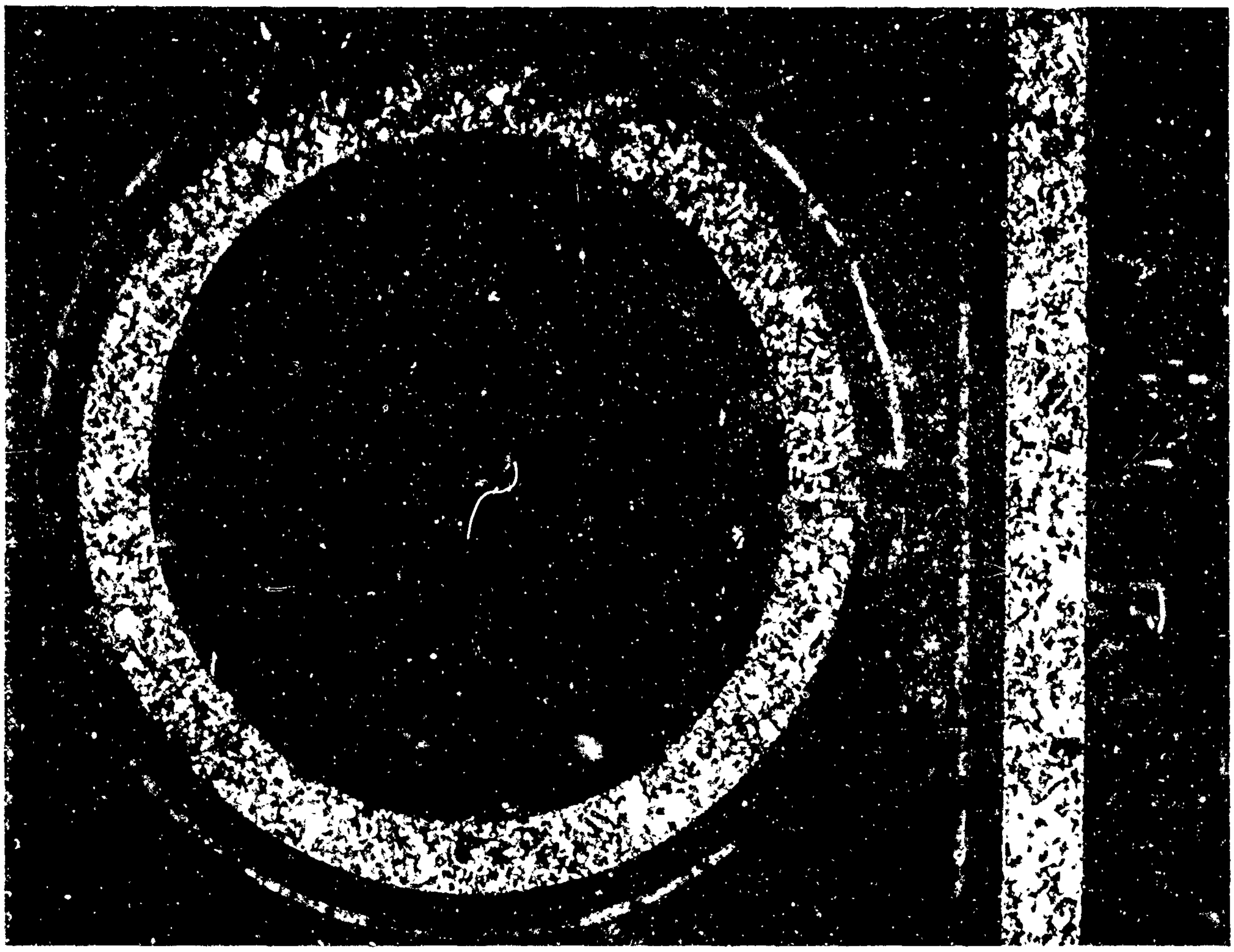


Figure 16

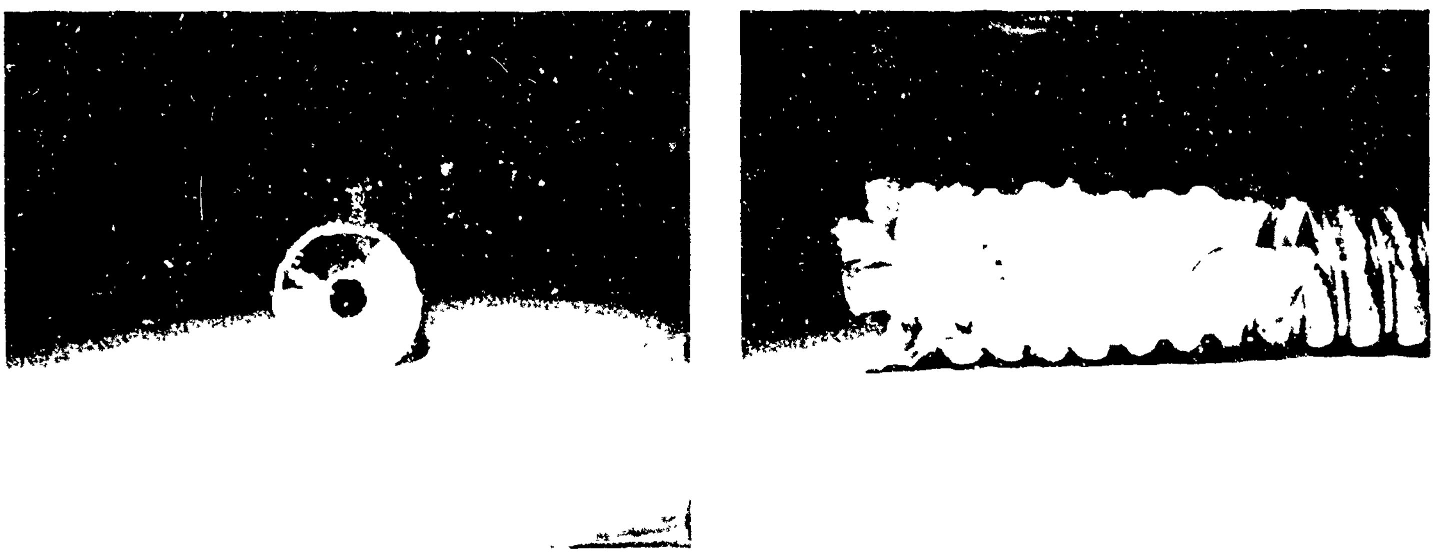
Etchants: Potassium Dichromate for Nickel — 30.5X Mag.
Ammonium Hydroxide & Hydrogen Peroxide for Silver
Ferric Chloride for Inconel

Photomacrograph of a silver-clad nickel over Inconel tube showing transverse and longitudinal cross sections.

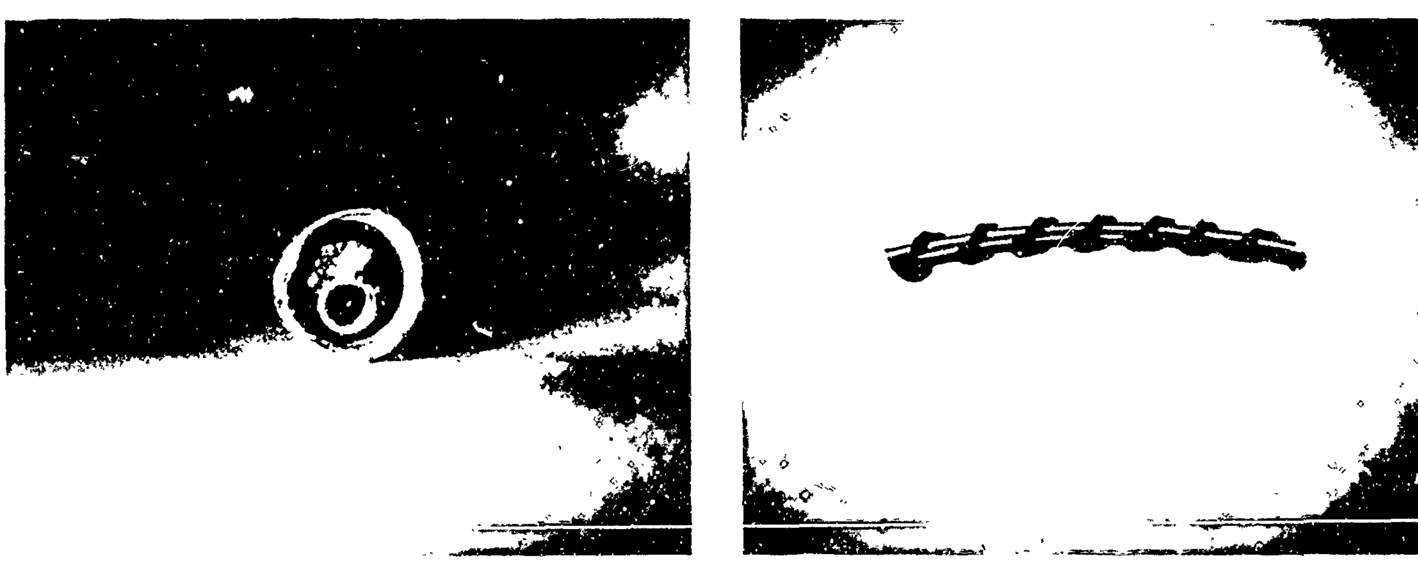
Figure 18.

CABLE "B"

350° C OVEN TESTS – EXPERIMENTAL MATERIALS



"FLUOROSINT" DIELECTRIC SECTION – AFTER 200 HRS. AT 350° C



GLASS FILLED TEFLON SECTION – AFTER 40 HRS. AT 350° C

EXPERIMENTAL CABLE

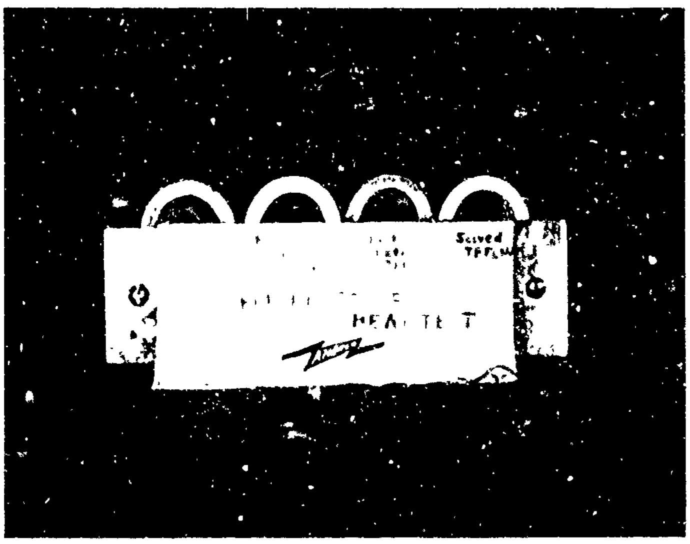
Figure 19.

CABLE "B"

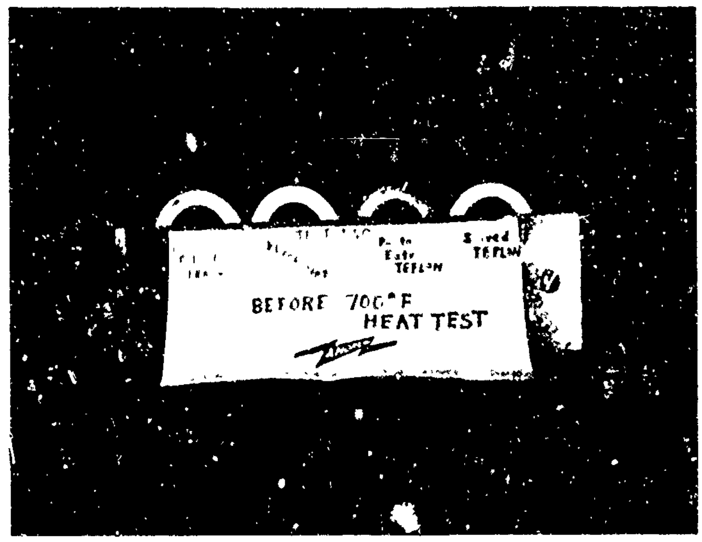
TESTING VARIOUS CABLE DIELECTRIC MATERIALS

GLASS-FILLED TEFLON – PASTE EXTRUDED TEFLON

FLUOROSINT – SCIVED* TEFLON

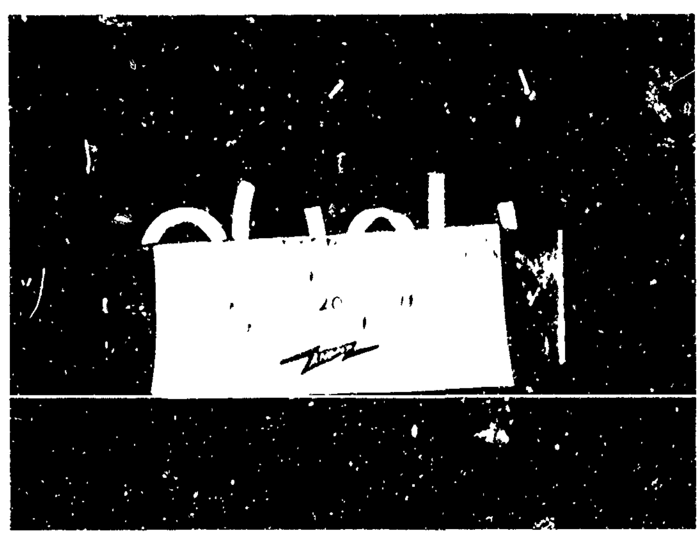


TEST NO. 1
BEFORE HEAT TEST



TEST NO. 2
BEFORE HEAT TEST

TEST NO. 1
AFTER 16.5 HRS. AT 700° F



TEST NO. 2
AFTER 20 HRS. AT 700° F

* Skived Teflon

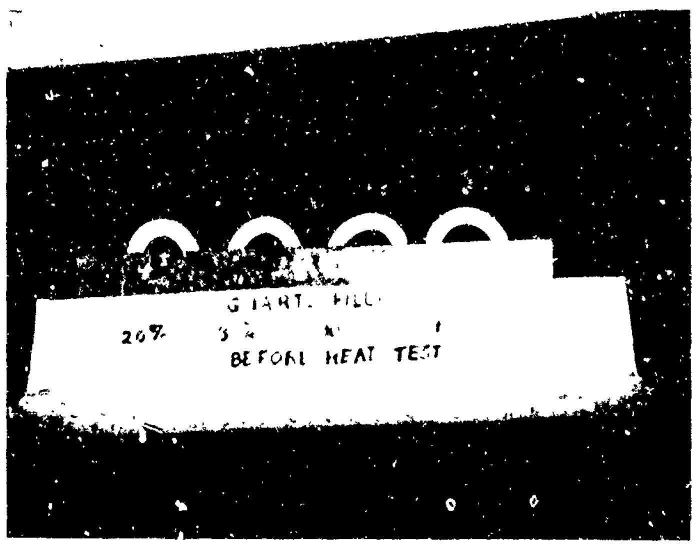
Figure 20.

CABLE "B"

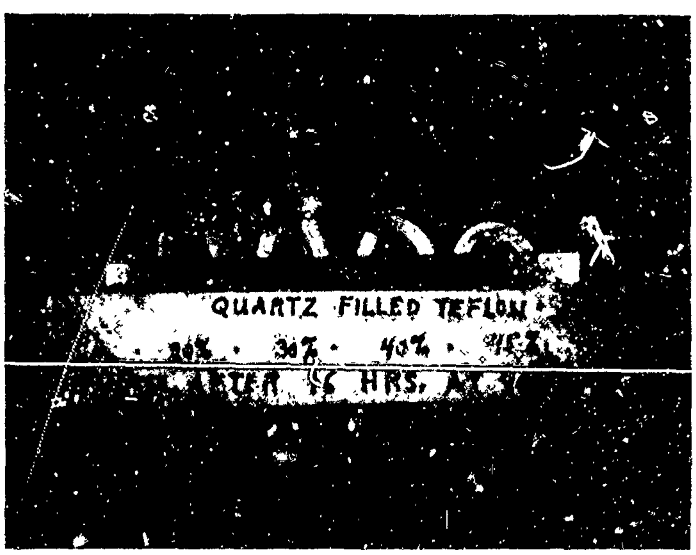
DETERMINATION OF OPTIMUM FILLER CONTENT

QUARTZ-FILLED TEFLON

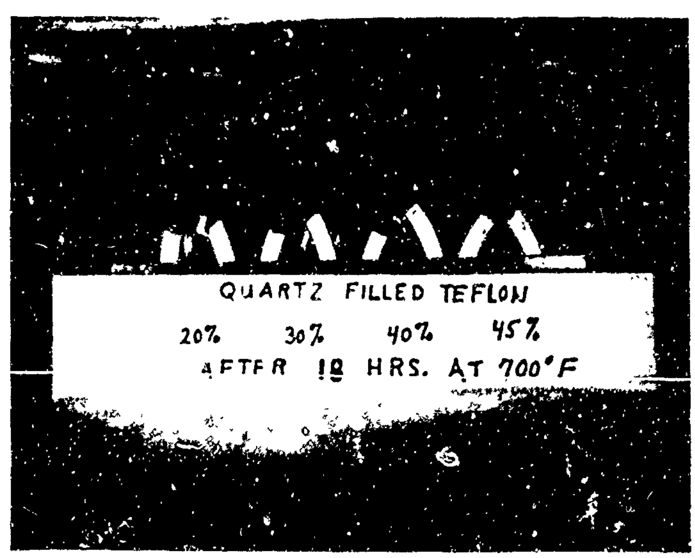
TEST NO. 1



BEFORE HEAT TEST



AFTER 16 HRS. AT 700° F



AFTER 18 HRS. AT 700° F

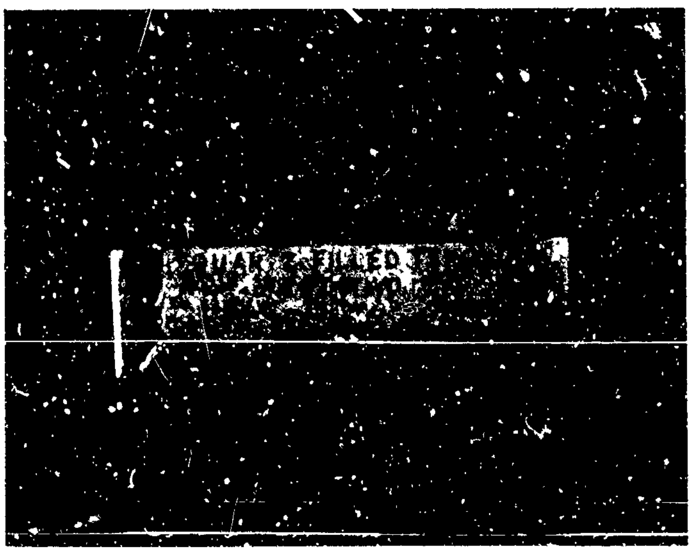
Figure 21.

CABLE "B"

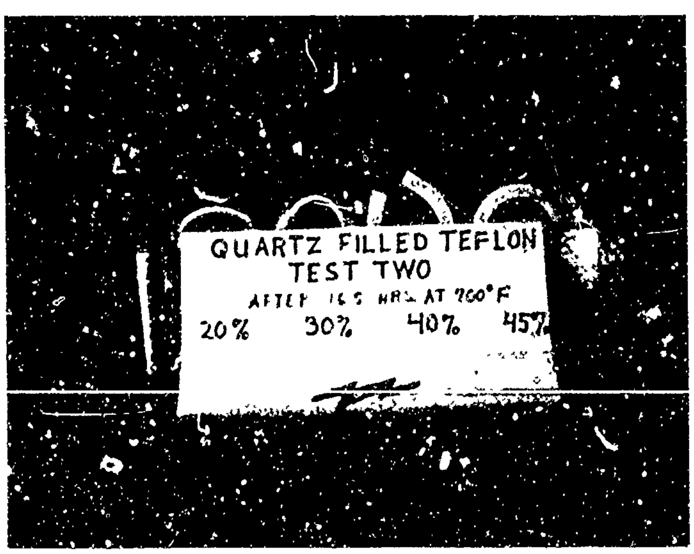
DETERMINATION OF OPTIMUM FILLER CONTENT

QUARTZ-FILLED TEFLON

TEST NO. 2



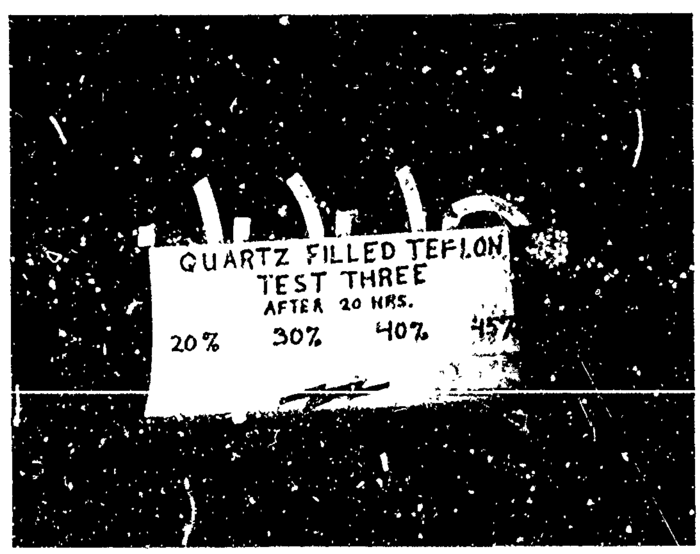
BEFORE HEAT TEST



AFTER 16.5 HRS. AT 700° F

TEST NO. 3

BEFORE HEAT TEST



AFTER 20 HRS. AT 700° F

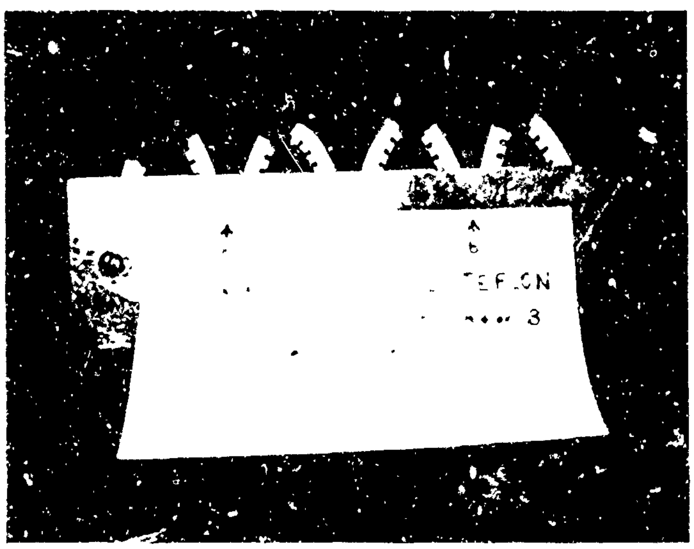
Figure 22.

CABLE "B"

DETERMINATION OF OPTIMUM NOTCH CUT OUT

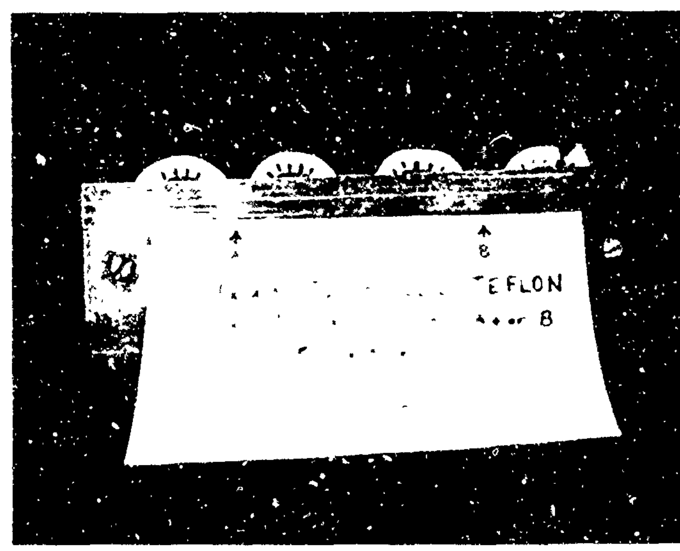
45% QUARTZ-FILLED TEFLON

200 HOUR HEAT TEST AT 700° F



NOTCH DEPTH: 5/64 IN.

ALL SAMPLES BROKE WITHIN 2 HRS.

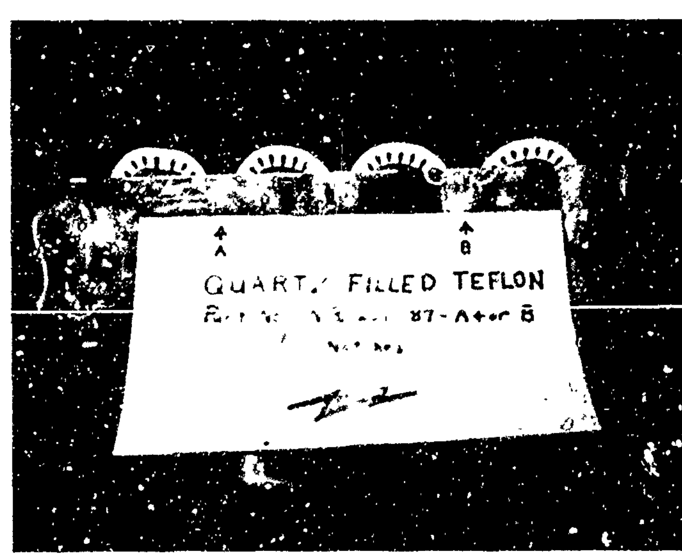


NOTCH DEPTH: 3/32 IN.

ONE SAMPLE BROKE WITHIN 2 HRS.

NOTCH DEPTH: 5/64 IN.

ONE SAMPLE BROKE WITHIN 2 HRS.



NOTCH DEPTH: 9/64 IN.

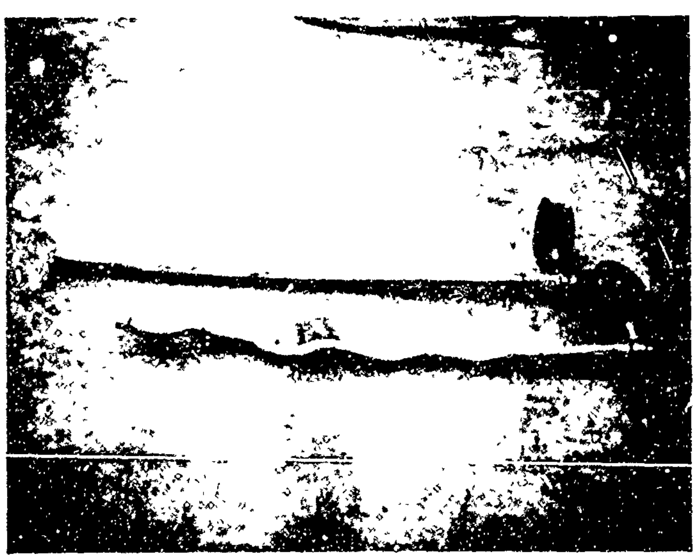
ALL SAMPLES SURVIVED HEAT TEST

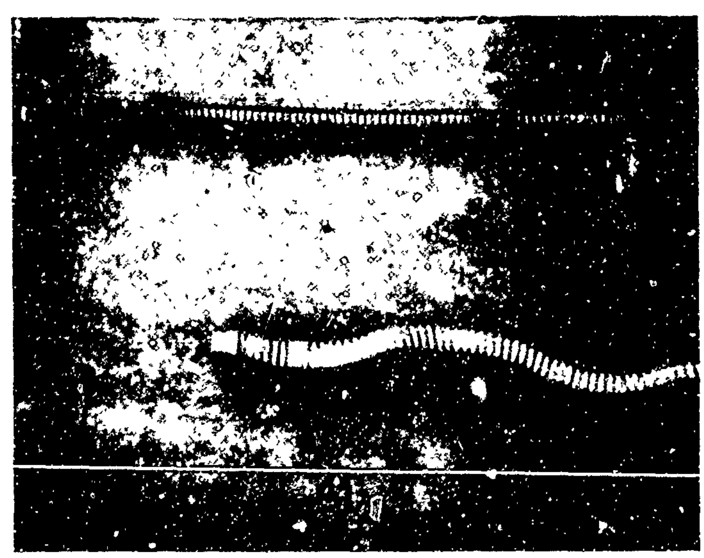
Figure 23.

CABLE "B"

PRESSURE TESTS

PRESSURE TESTING 50 FT. COIL OF 7/8" H.T. HELIAX



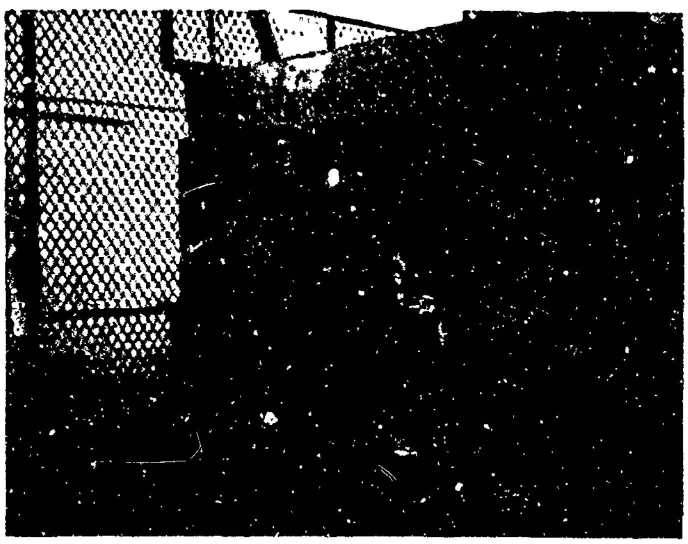


AFTER 100 HRS. AT 350° C (CABLE PRESSURE 80 PSIG AT 350° C)
DISTORTED CABLE HAS AN ALUMINUM OUTER CONDUCTOR
STRAIGHT CABLE HAS AN OFHC COPPER OUTER CONDUCTOR
BOTH CABLES HAVE CAPTIVATED COPPER INNER CONDUCTORS
BOTH CABLES WERE INITIALLY STRAIGHT

Figure 24.

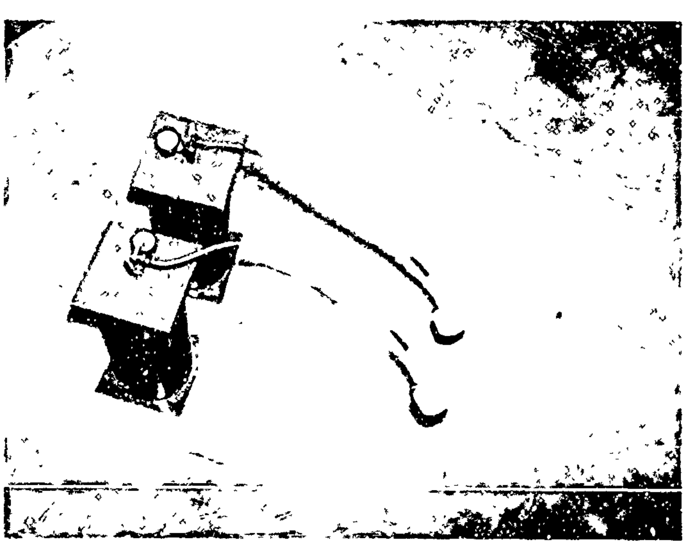
CABLE "B"

GAS BARRIER THERMAL SHOCK TEST



OVEN TEST: 350° C

COLD CHAMBER TEST:-65° C



JUST OUT OF COLD CHAMBER

CLOSE UP VIEW OF GAS BARRIERS

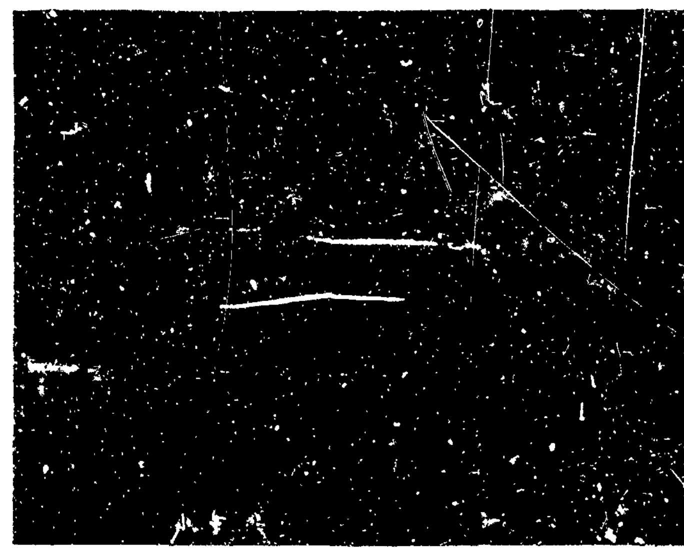
TYPE 26450
GAS BARRIER

Figure 25.

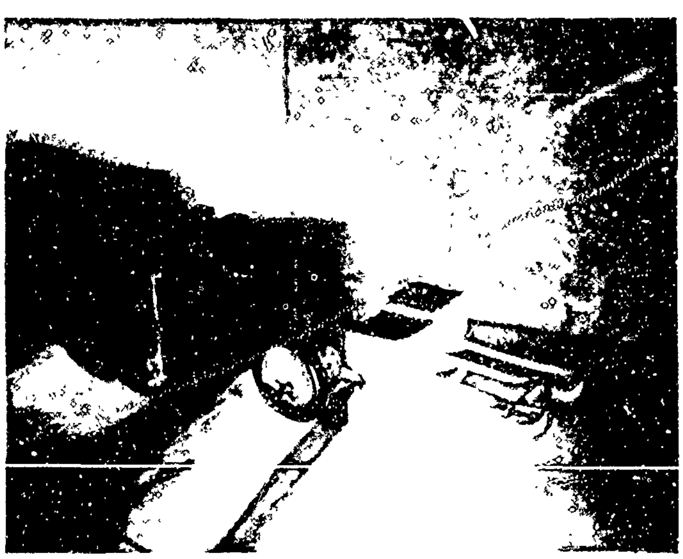
CABLE "A" & "B"

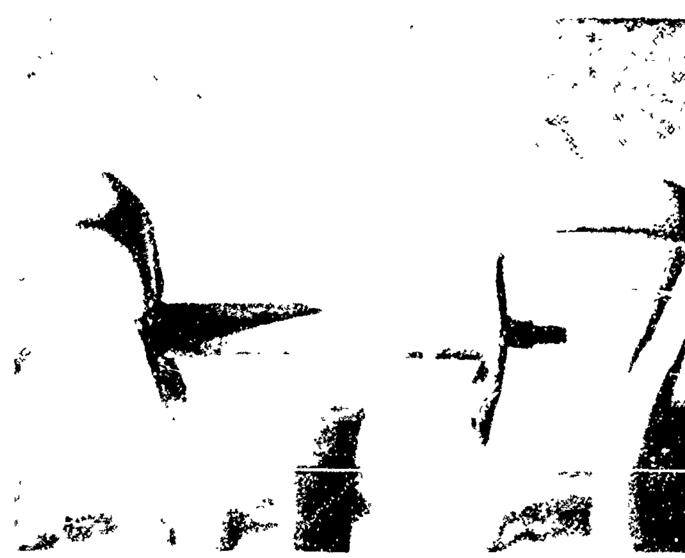
CONNECTOR TESTS

OVEN TEST



OUT OF OVEN





INNER CONNECTOR CONTACT TEST

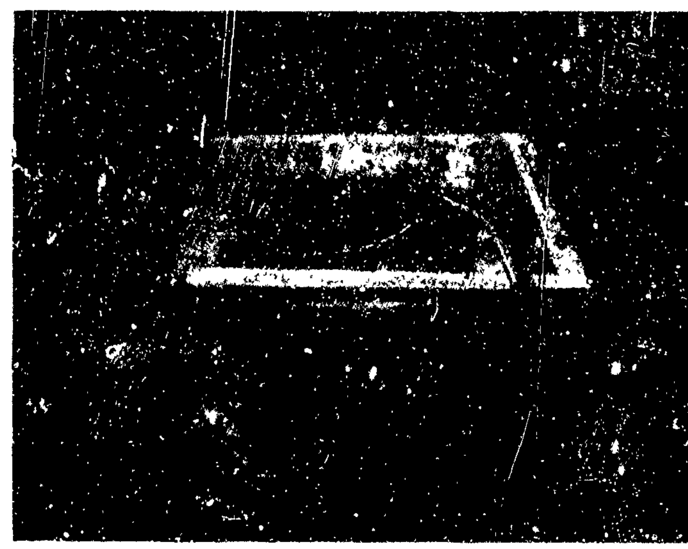
Figure 26.

CABLE "B"

ENVIRONMENTAL TESTING

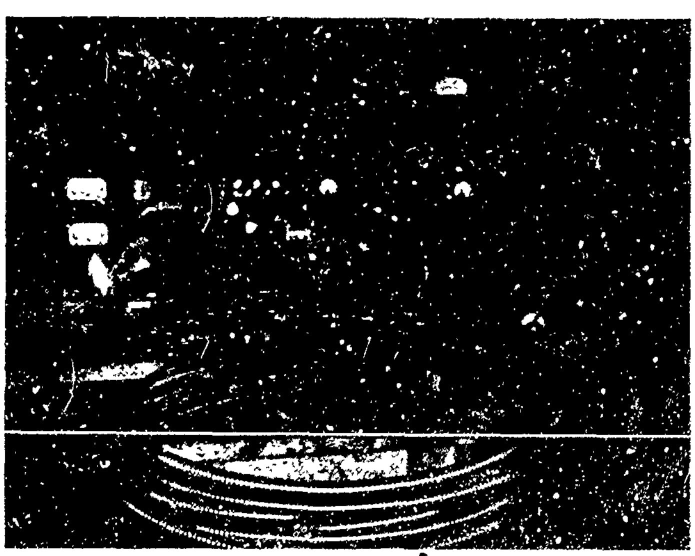
HIGH TEMPERATURE OVEN

ATTENUATION MEASUREMENTS ON
A 50 FT. LENGTH OF H.T. HELIAX

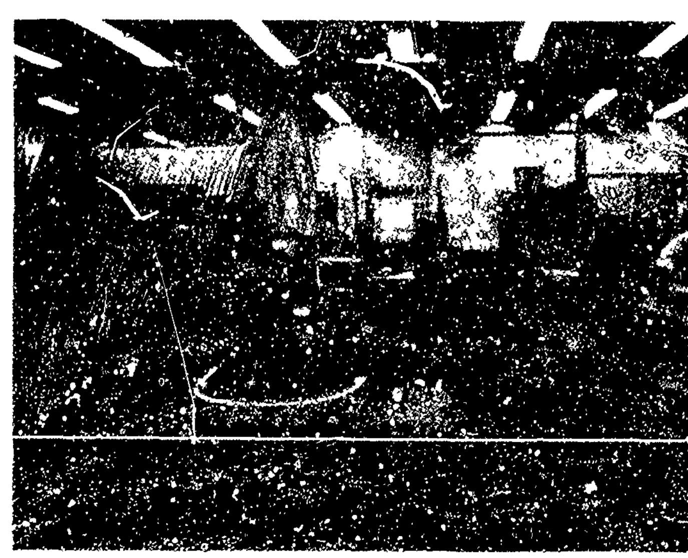


COLD CHAMBER

ATTENUATION MEASUREMENTS ON
A 50 FT. LENGTH OF H.T. HELIAX



SLOTTED LINE VSWR MEASUREMENTS



SWEEP VSWR MEASUREMENTS

TEST CABLES

7/8" HIGH TEMPERATURE

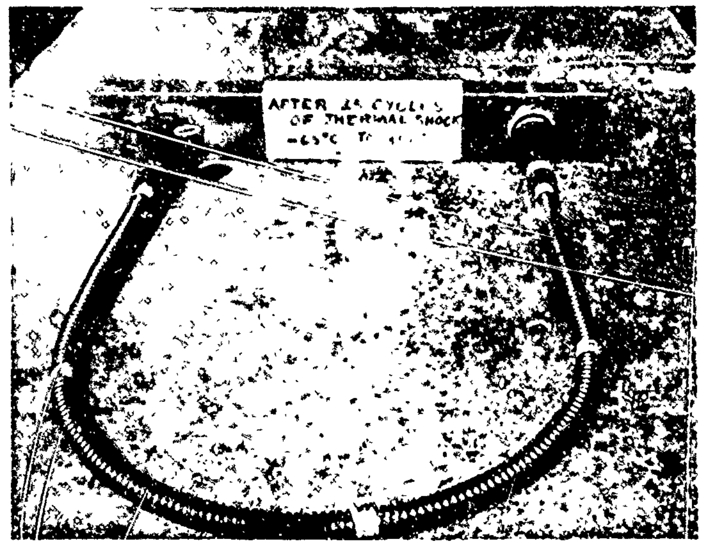
HELIAX

Figure 27.

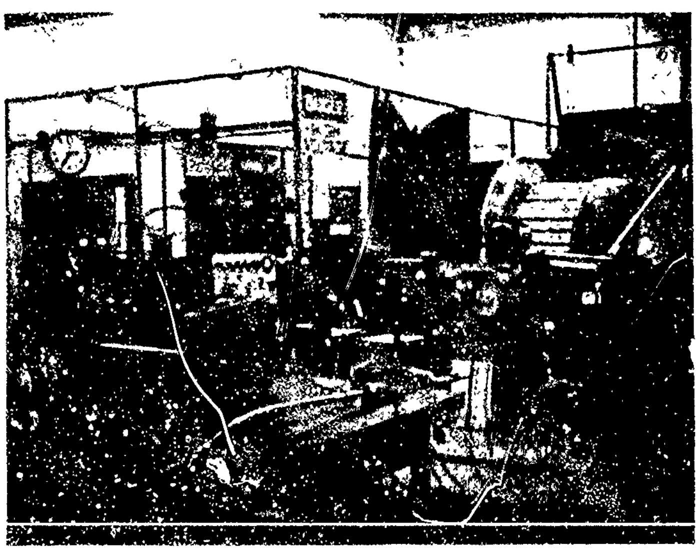
CABLE "B"

TESTING

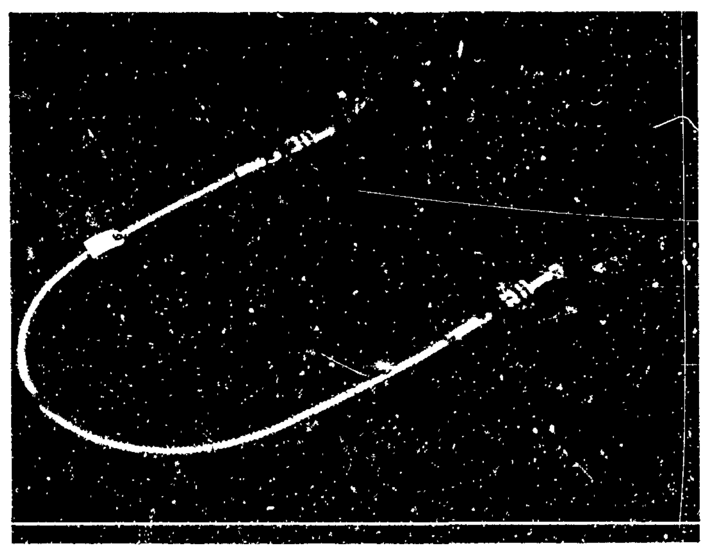
PRESSURE & ELECTRICAL TESTS
AT ELEVATED TEMPERATURES



TEST CABLE AFTER
25 CYCLES OF THERMAL SHOCK



ELECTRICAL MEASUREMENTS
AFTER 200 HOURS AT 350° C



SWEEP VSWR MEASUREMENTS ON
7/8" H.T. HELIAX WITH CONNECTORS
AND GAS BARRIERS

TEST CABLES

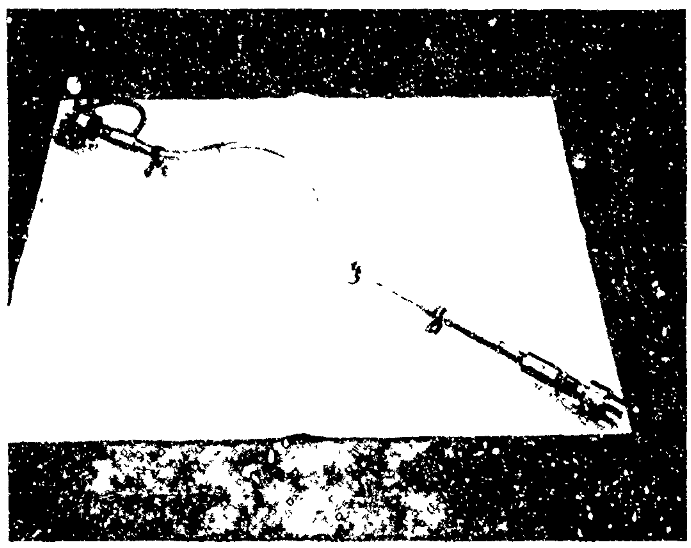
7/8" HIGH TEMPERATURE

HELIAX

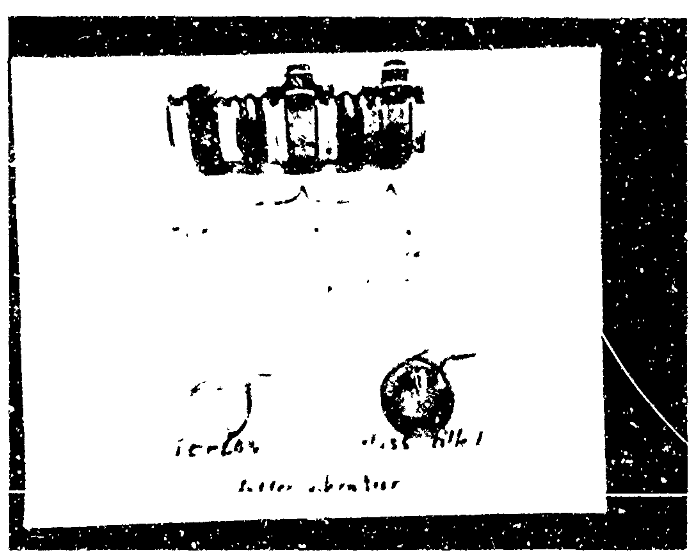
Figure 28.

CABLE "B"

VIBRATION & HEAT TESTS



TEST CABLE AND CLAMPING ARRANGEMENT



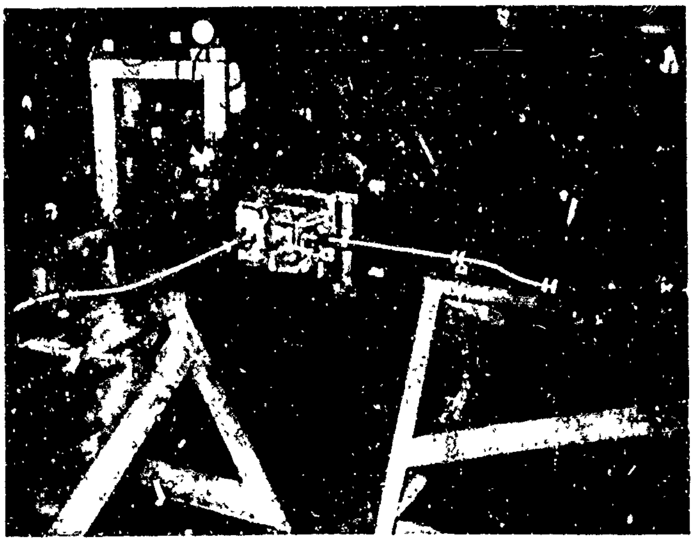
HEAT & VIBRATION TESTS ON CLAMP INSERT

TEST CABLE
7/8" HIGH TEMPERATURE HELIAX

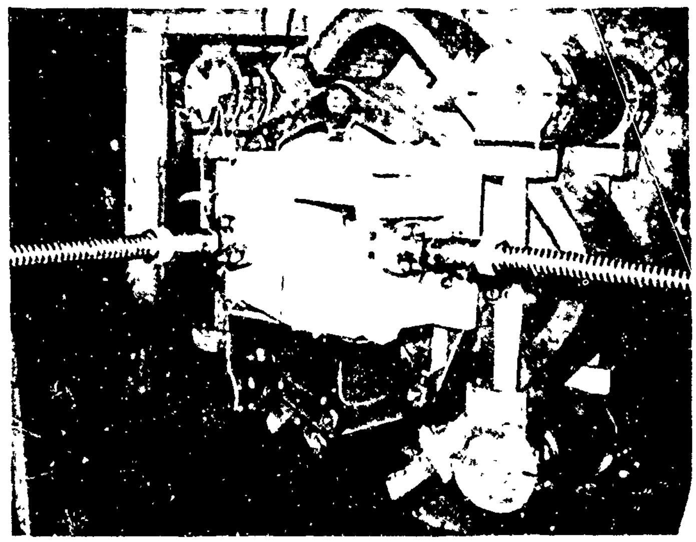
Figure 29.

CABLE "B"

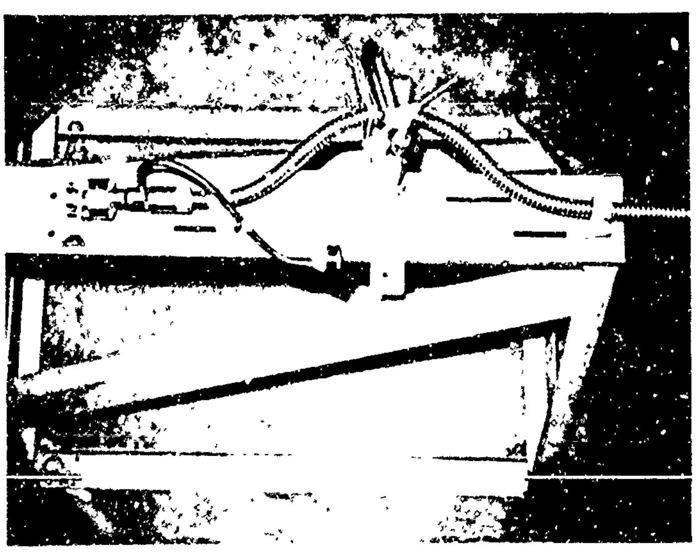
VIBRATION TESTS



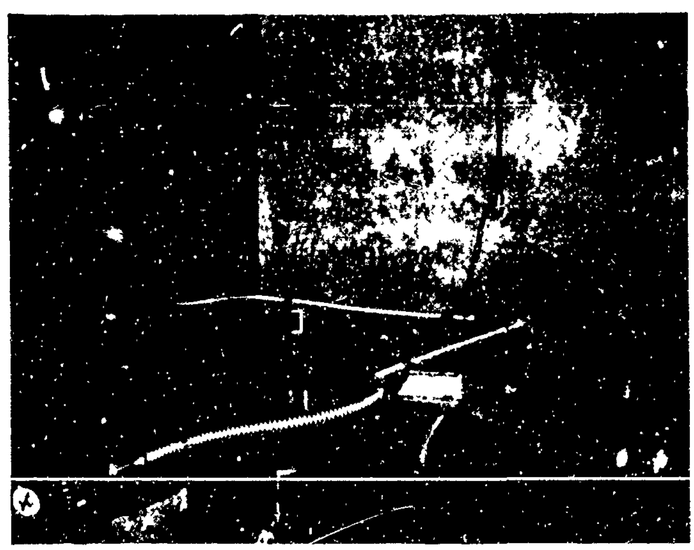
"SPEAKER" TYPE VIBRATOR



CLOSE-UP VIEW OF SHAKE TABLE



CLOSE-UP VIEW OF CABLE CLAMPING

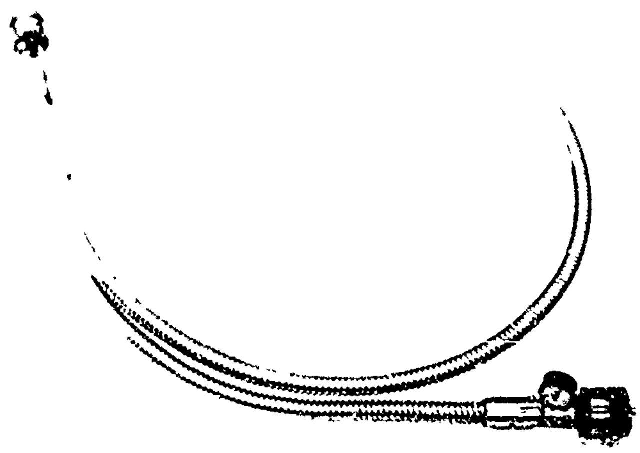


MECHANICAL TYPE VIBRATOR

TEST CABLE
7/8" HIGH TEMPERATURE **HELIAX**

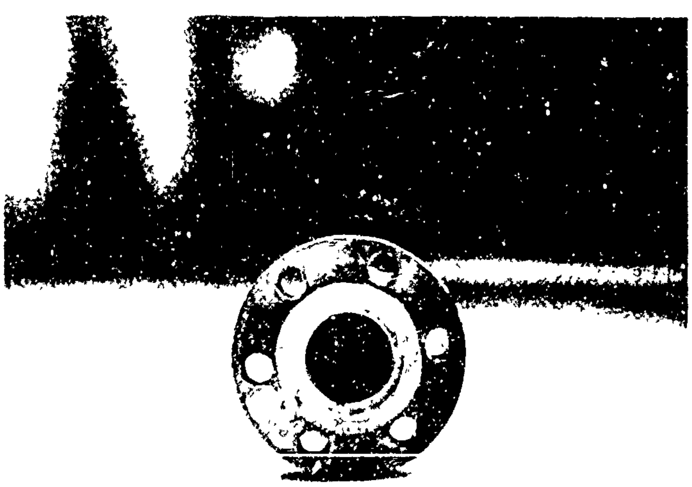
Figure 30.

CABLE "B"
ASSEMBLY

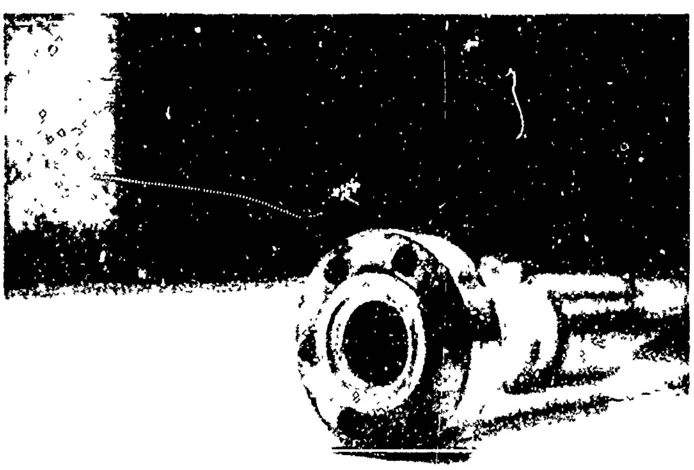


CABLE ASSEMBLY

CONNECTOR



CONNECTOR



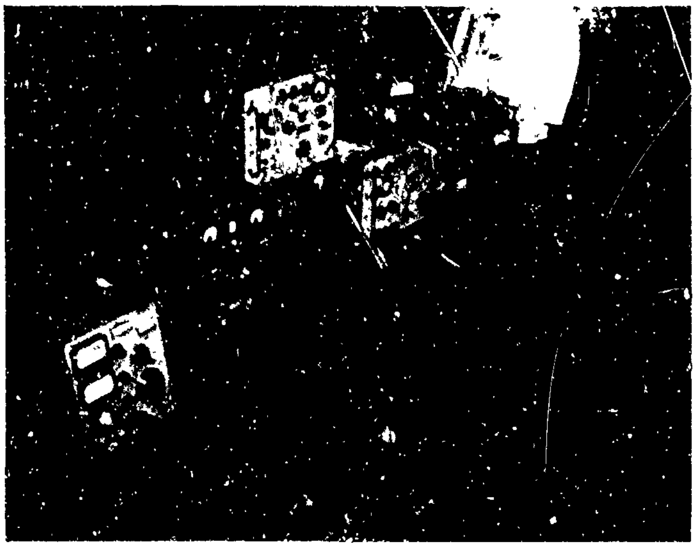
CONNECTOR

PROTOTYPE CABLE

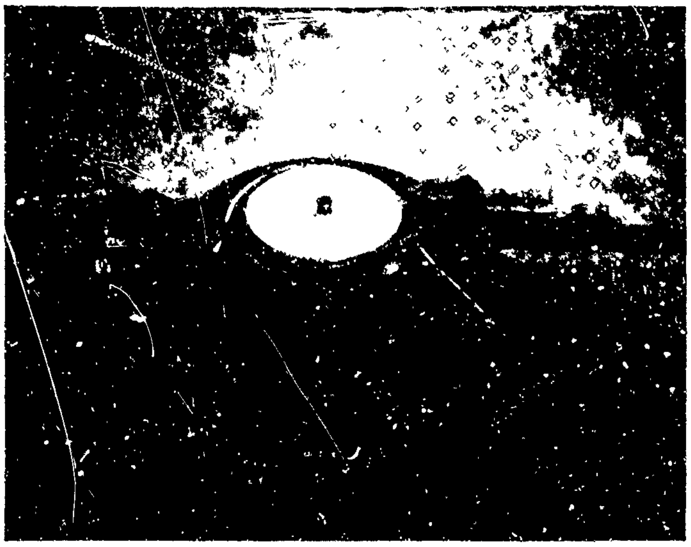
7/8" HIGH TEMPERATURE

Figure 31.

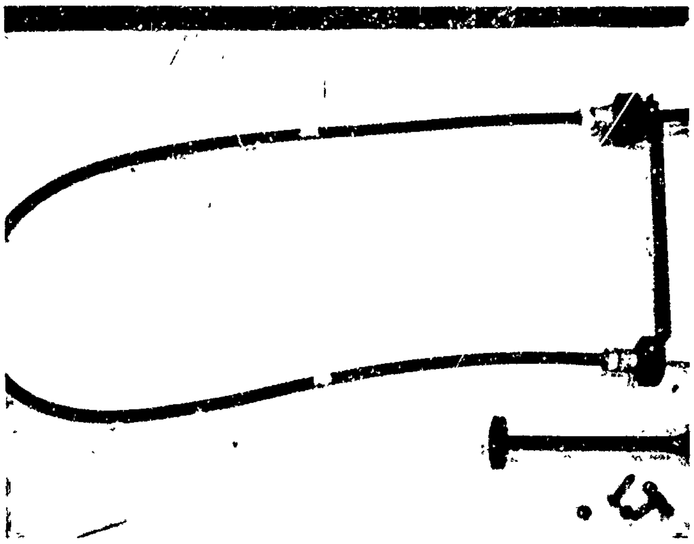
CABLE "A"
TESTING



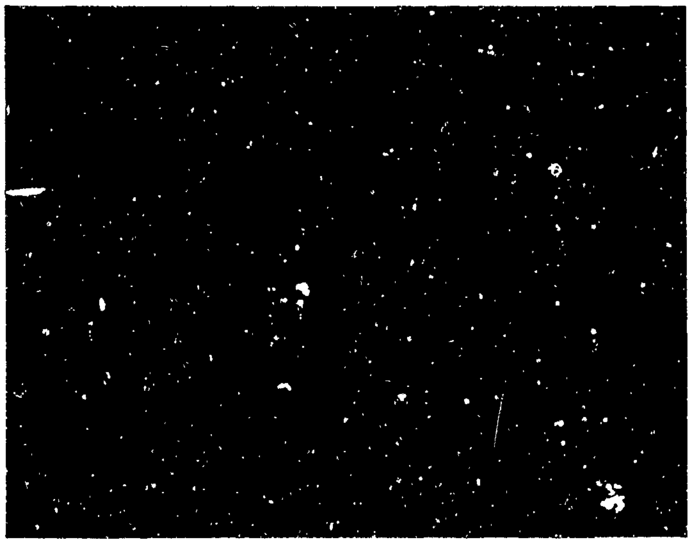
ATTENUATION MEASUREMENTS



REVERSE BEND TESTS



THERMAL SHOCK CABLE
AFTER 10 CYCLES

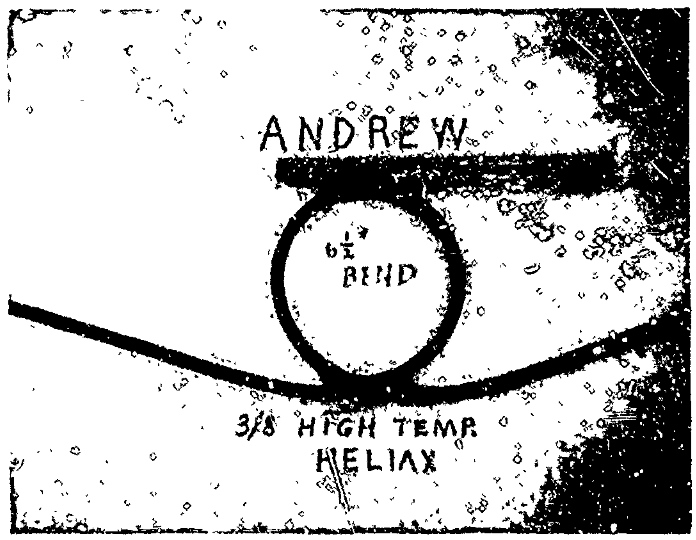


50 FT. LENGTH OF CABLE
COILED ON A 3 FT. DIAMETER

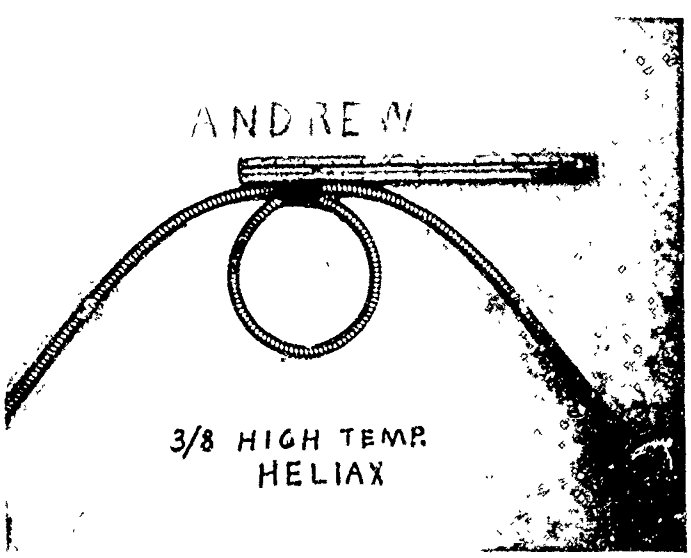
TEST CABLE
3/8" HIGH TEMPERATURE HELIAX

CABLE "A"

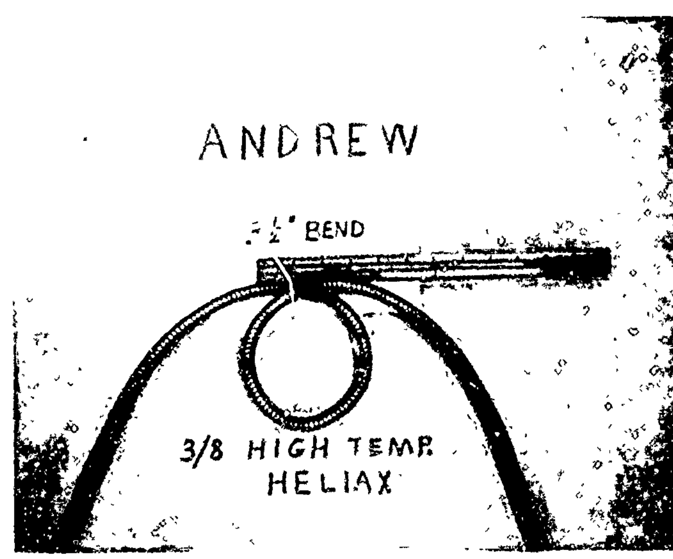
VSWR AND BEND RADIUS TESTS



6½" DIAMETER BEND



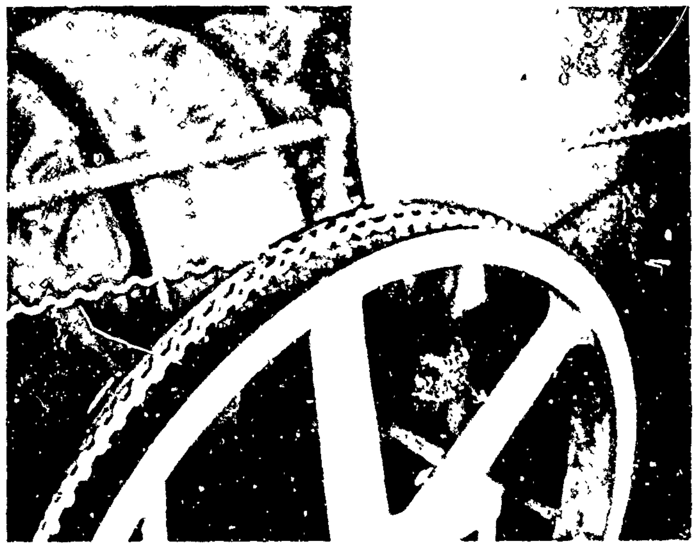
4½" DIAMETER BEND



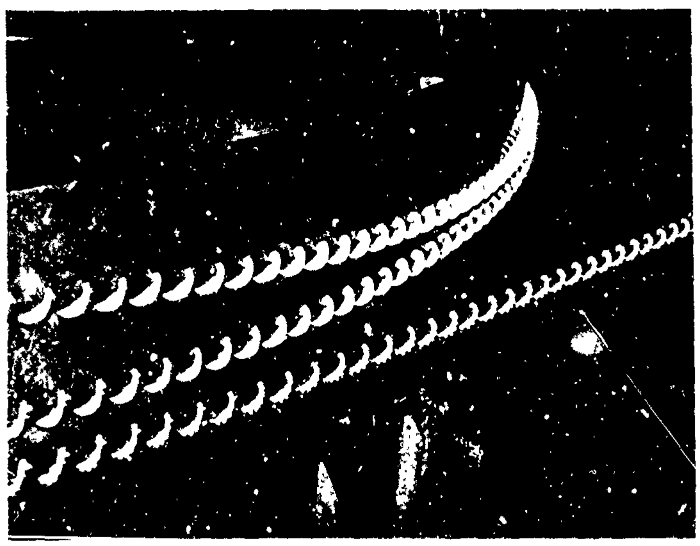
3½" DIAMETER BEND

TEST CABLE
3/8" HIGH TEMPERATURE **HELIAX**

CABLE FABRICATION



CABLE "A" INNER CONDUCTOR ASSEMBLY

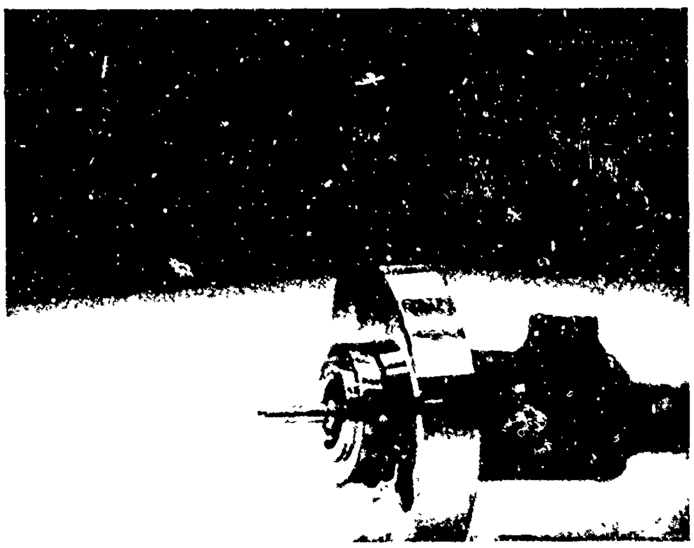


CABLE "B" INNER CONDUCTOR ASSEMBLY

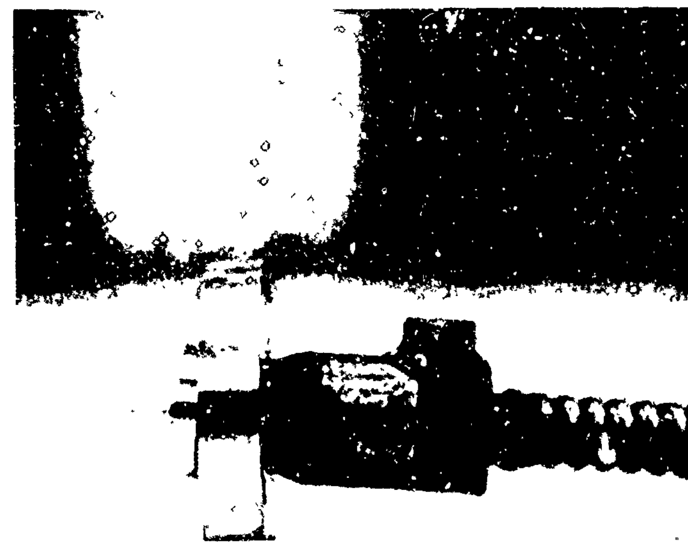
Figure 34

CABLE "A"

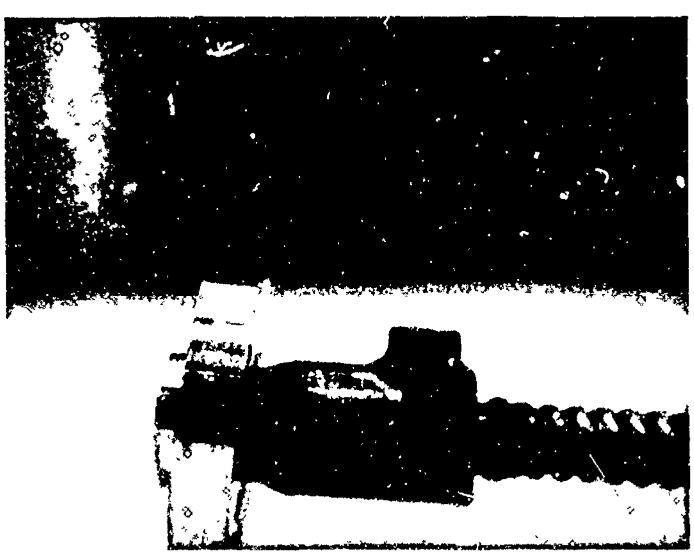
CONNECTORS



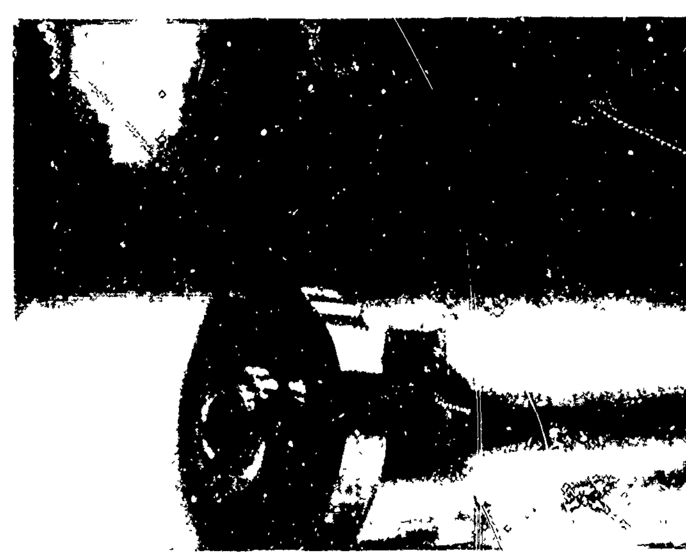
MALE CONNECTOR



MALE CONNECTOR



FEMALE CONNECTOR



FEMALE CONNECTOR

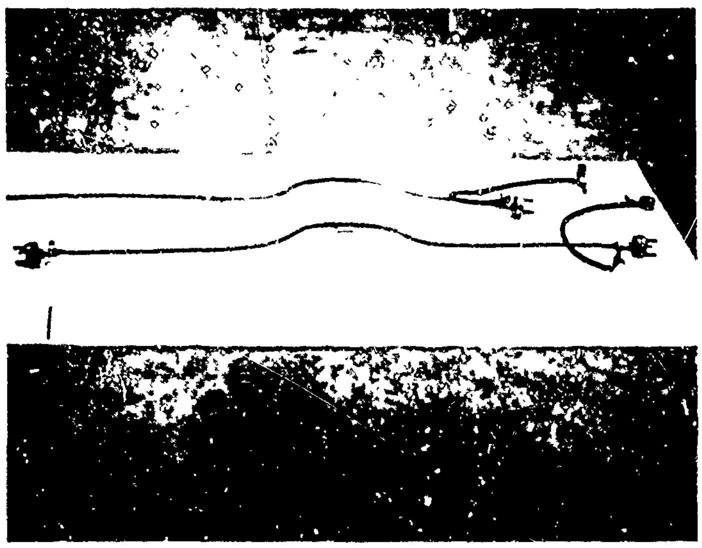
CONNECTORS

3/8" HIGH TEMPERATURE

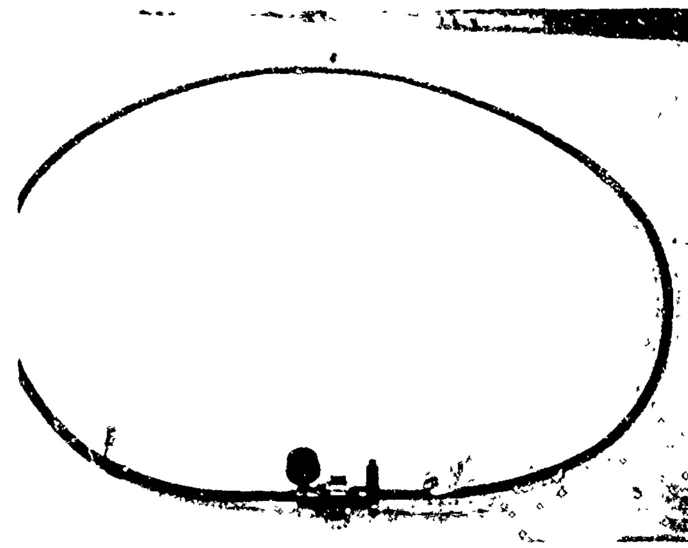
HELIAX

CABLE "A"

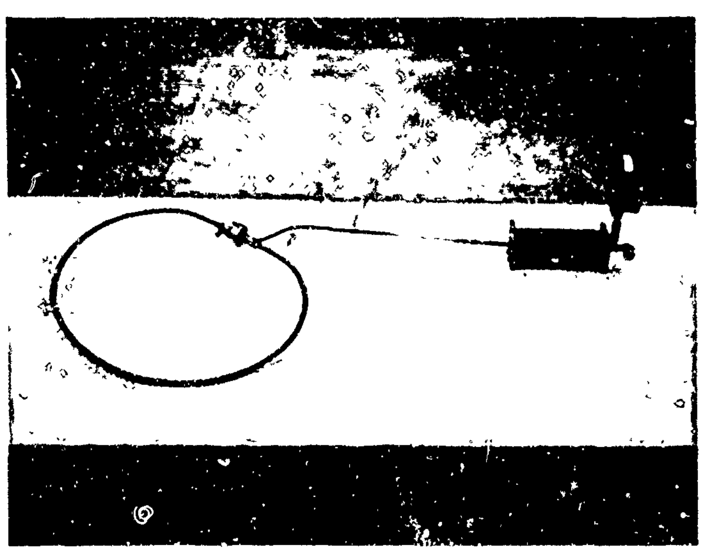
CABLE ASSEMBLIES

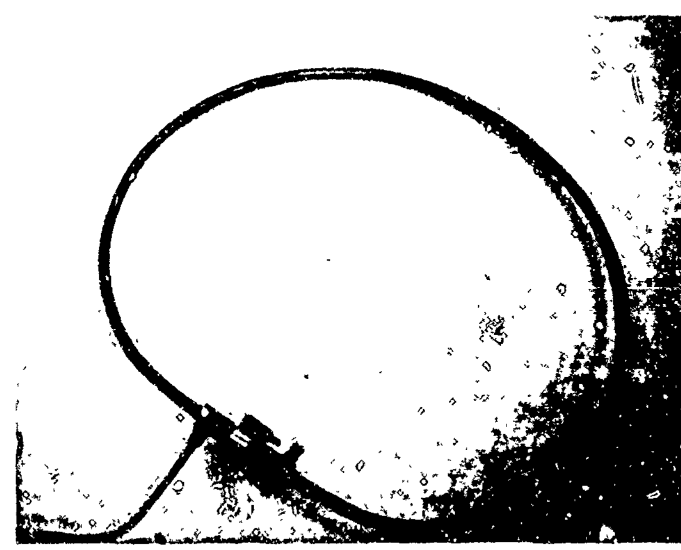


VIBRATION CABLE ASSEMBLIES



PROTOTYPE CABLE ASSEMBLY



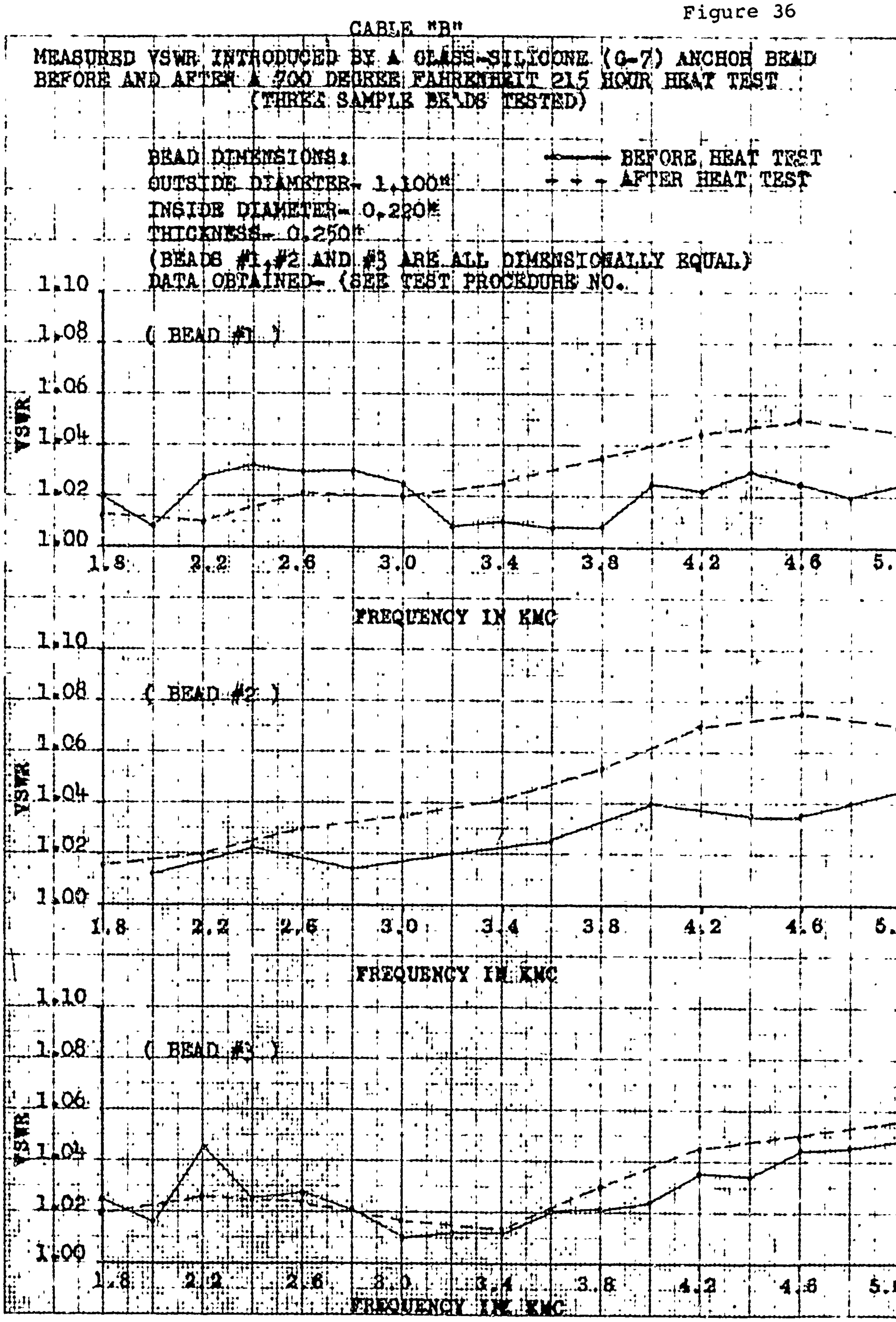


THERMAL SHOCK TEST CABLE

TEST CABLE
3/8" HIGH TEMPERATURE **HELIAX**

5.

Figure 36



CABLE "B"
MEASURED VSWR INTRODUCED BY A GLASS-SILICONE (G-7) ANCHOR BEAD
BEFORE AND AFTER A 700 DEGREE FAHRENHEIT 215 HOUR HEAT TEST
(THREE SAMPLE BEADS TESTED)
BEAD DIMENSIONS:
OUTSIDE DIAMETER- 1.100"
INSIDE DIAMETER- 0.220"
THICKNESS- 0.250"
(BEADS #1, #2 AND #3 ARE ALL DIMENSIONALLY EQUAL)
DATA OBTAINED- (SEE TEST PROCEDURE NO.
BEFORE HEAT TEST
AFTER HEAT TEST
(BEAD #1)
(BEAD #2)
(BEAD #3)
VSWR
1.10
1.08
1.06
1.04
1.02
1.00
1.8
2.2
2.6
3.0
3.4
3.8
4.2
4.6
5.0
FREQUENCY IN KMC

CABLE B

VSWR of Two Connectors Back - To - Back

Four (4) NEMA Grade G-7 Insulators

7/8" H. T. Connectors

600 to 5000 MC

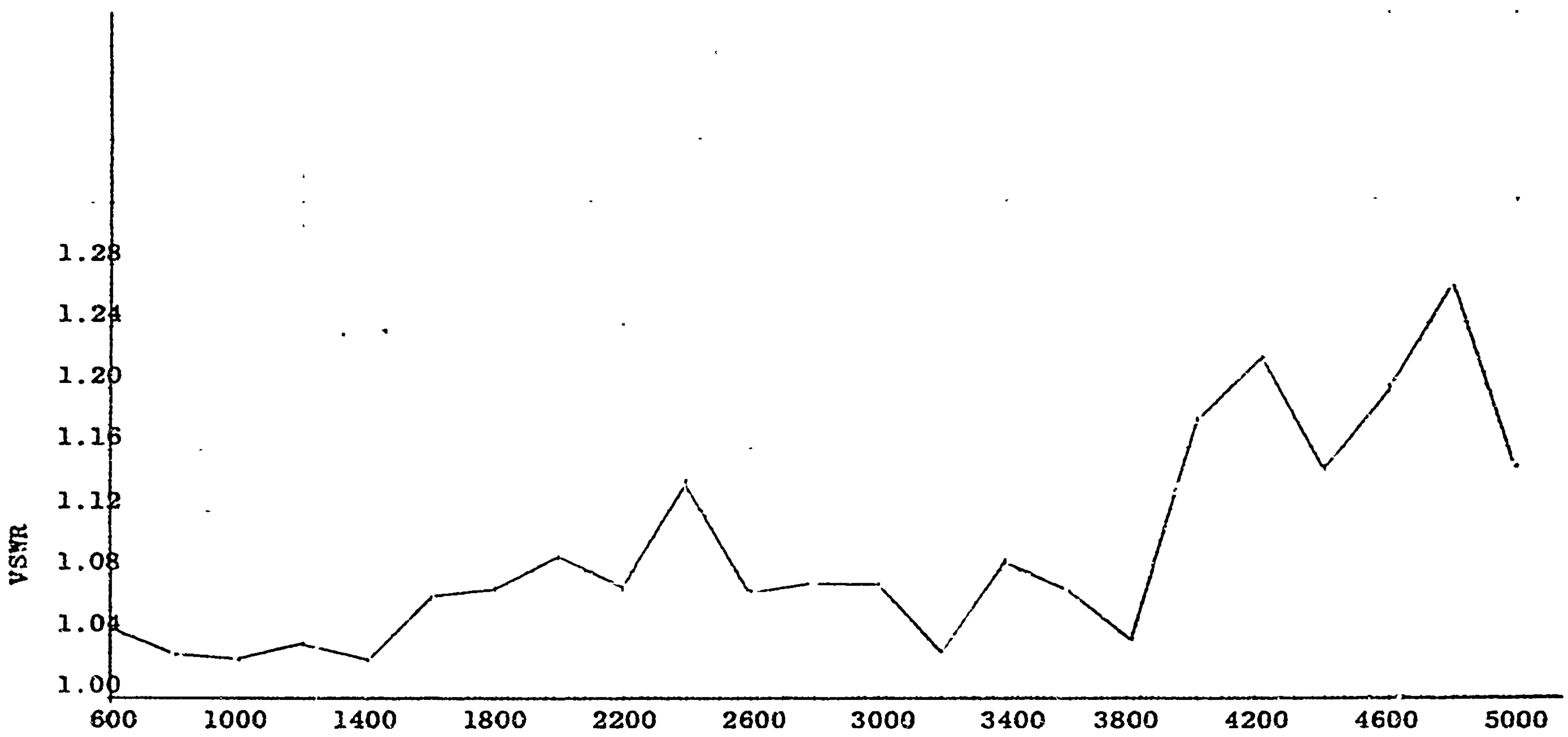


Figure 37

CABLE "B"

VSWR of a 50 ft. length of 7/8" H. T. HELIAX with connectors and gas barriers coiled on 30" diameter

7/8" H. T. HELIAX
400 to 2600 MC

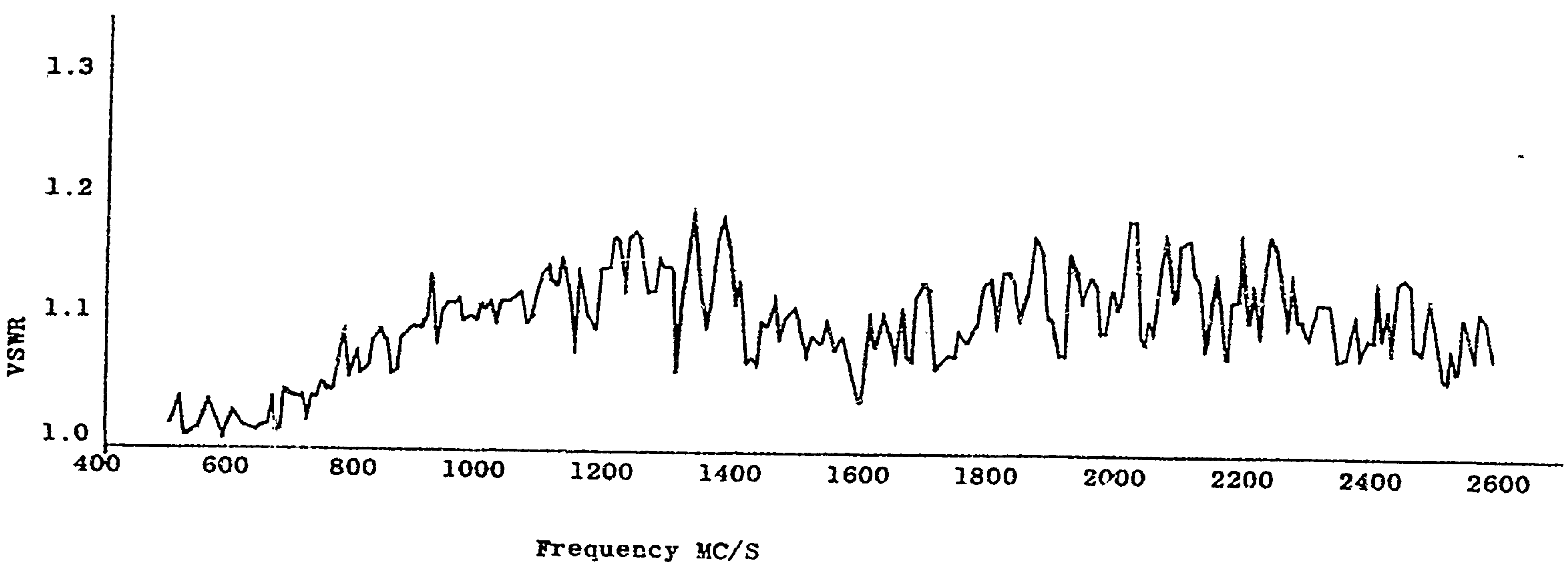


Figure 38.

Figure 39.

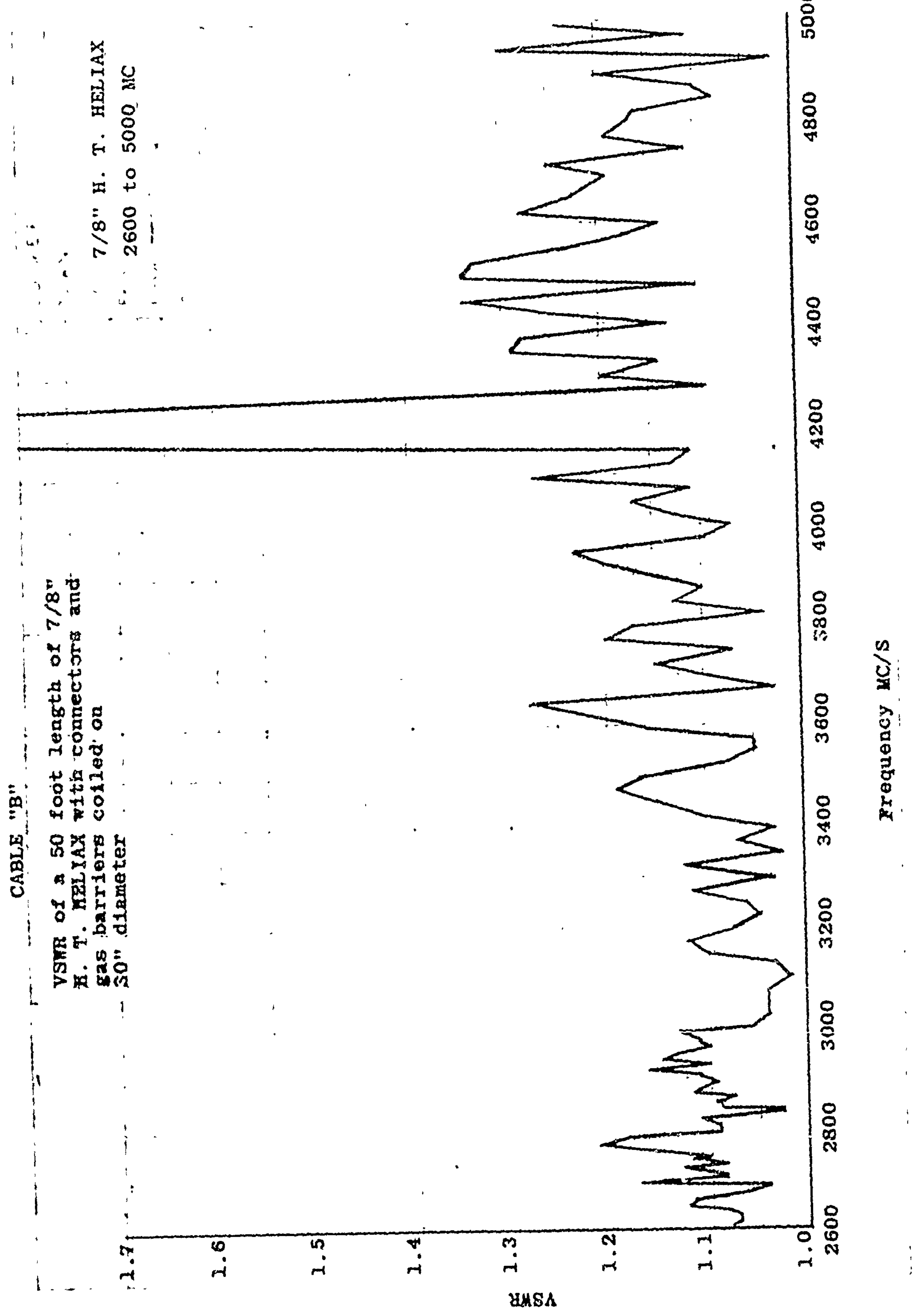
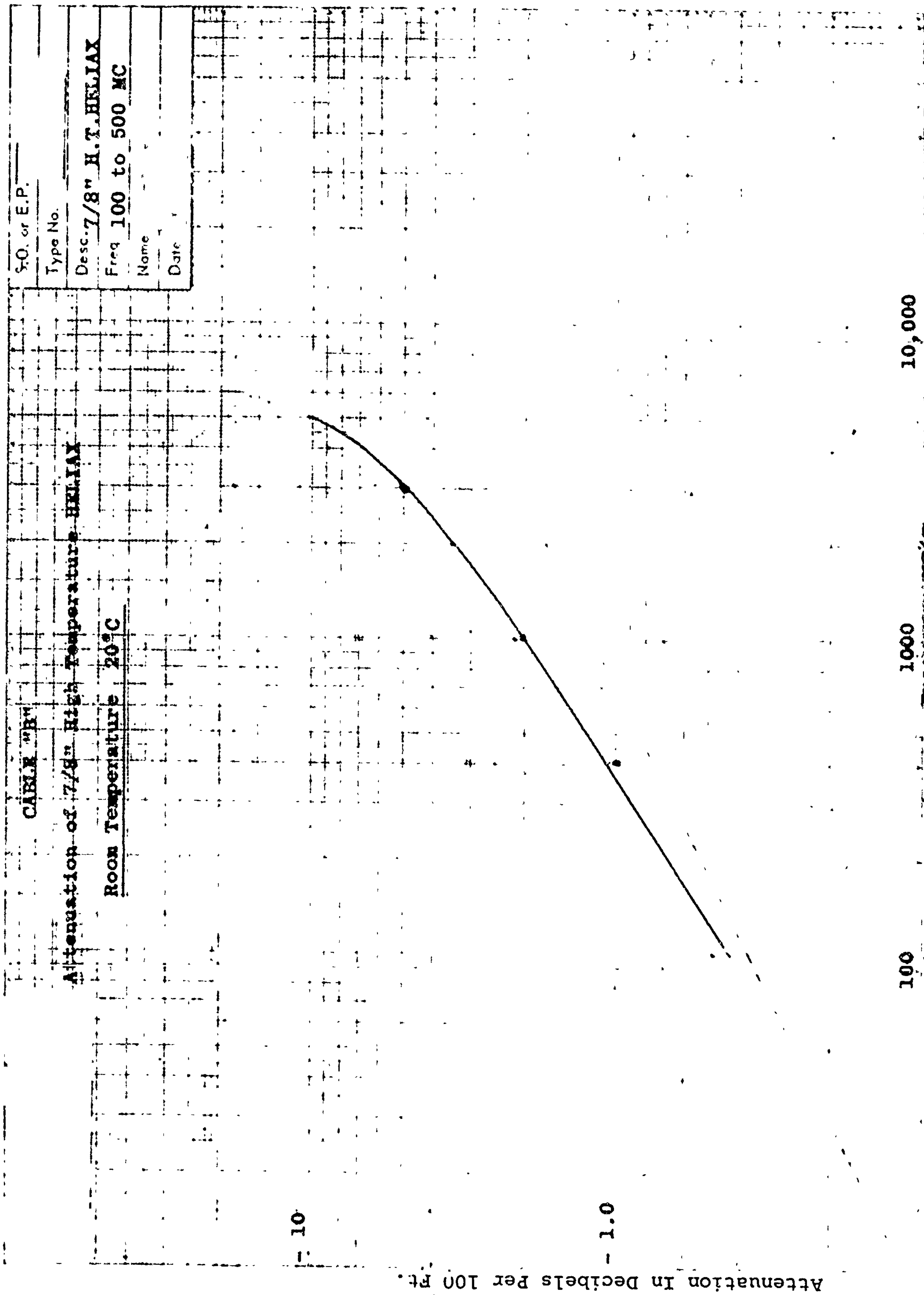

CABLE "B"
VSWR of a 50 foot length of 7/8" H. T. HELIAX with connectors and gas barriers coiled on 30" diameter
7/8" H. T. HELIAX
2600 to 5000 MC
VSWR
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
Frequency MC/S

Figure 40.



CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Room Temperature 20°C
S.O. or E.P.
Type No.
Desc. 7/8" H.T.HELIAX
Freq 100 to 500 MC
Name
Date
10
1.0
Attenuation In Decibels Per 100 Ft.
100
1000
10,000
Frequency MC/S

Figure 41.

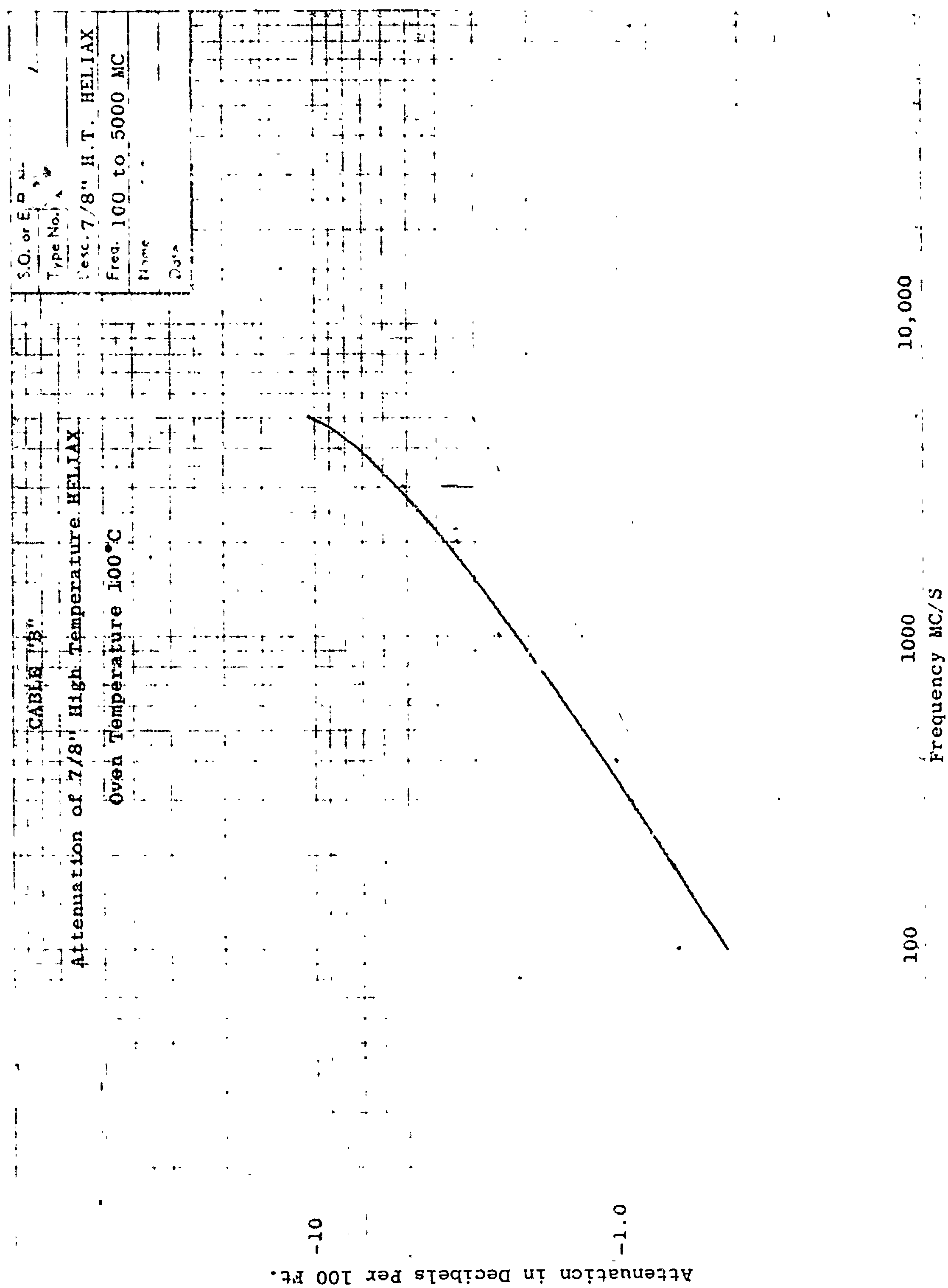
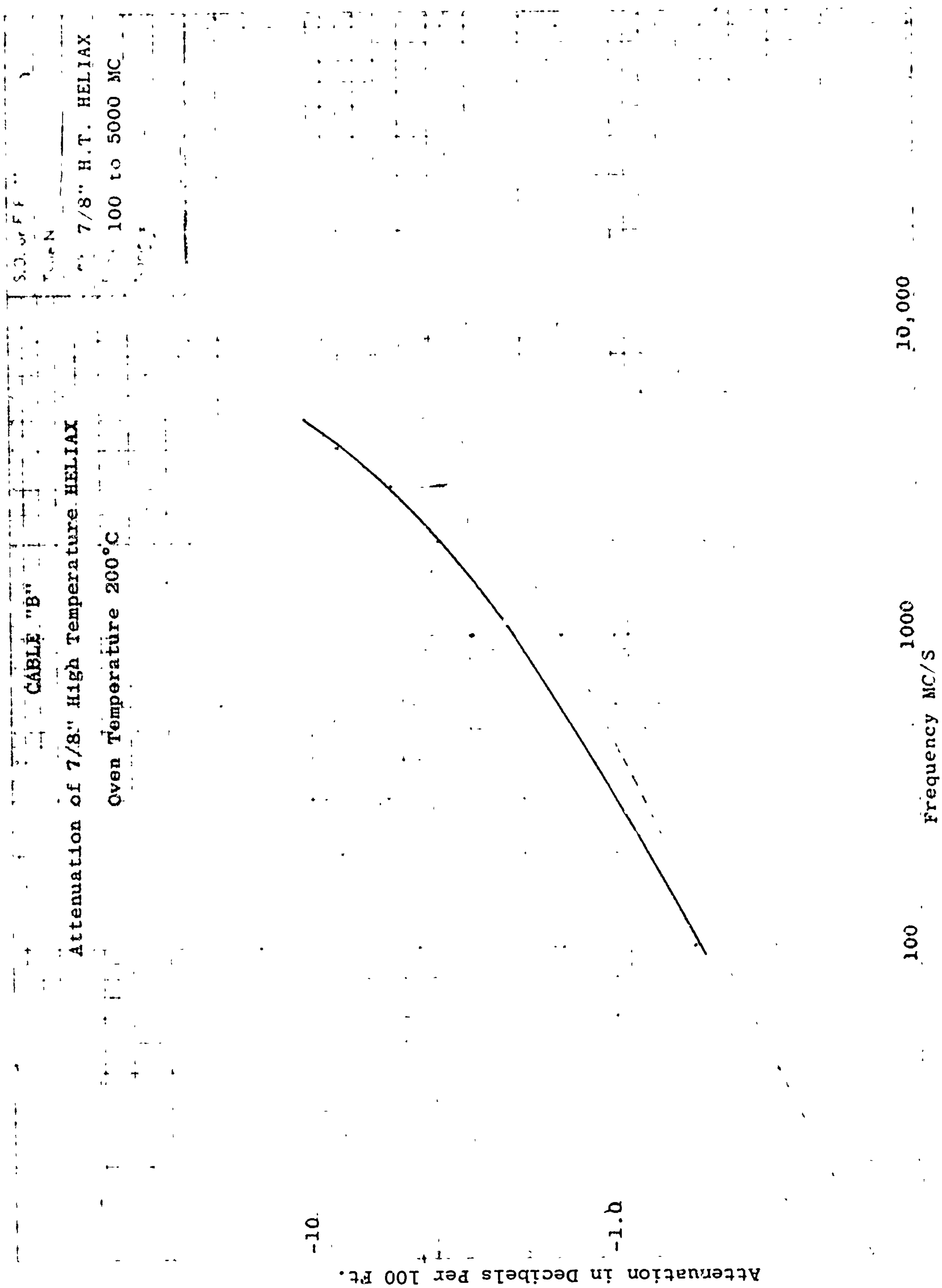
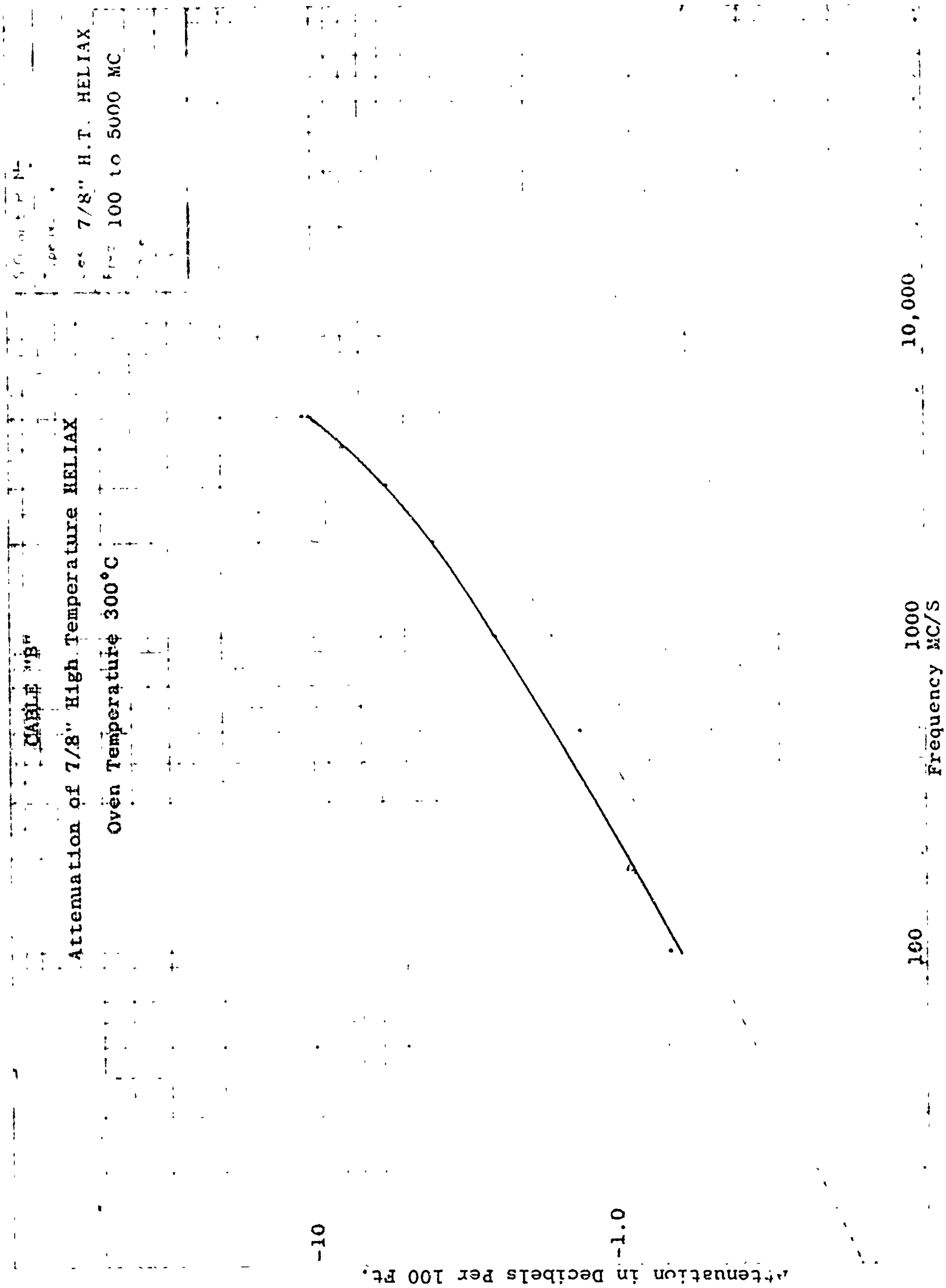

CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Oven Temperature 100°C
S.O. or E.P. No.
Type No.
Desc. 7/8" H.T. HELIAX
Freq. 100 to 5000 MC
Name
Date
100
1000
10,000
Frequency MC/S
10
1.0
Attenuation in Decibels Per 100 Ft.

Figure 42.



CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Oven Temperature 200°C
7/8" H.T. HELIAX
100 to 5000 MC
-10
-1.0
100
1000
10,000
Frequency MC/S
Attenuation in Decibels Per 100 Ft.

Figure 43.


CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Oven Temperature 300°C
7/8" H.T. HELIAX
100 to 5000 MC
10
1.0
100
1000
10,000
Frequency MC/S
Attenuation in Decibels Per 100 Ft.

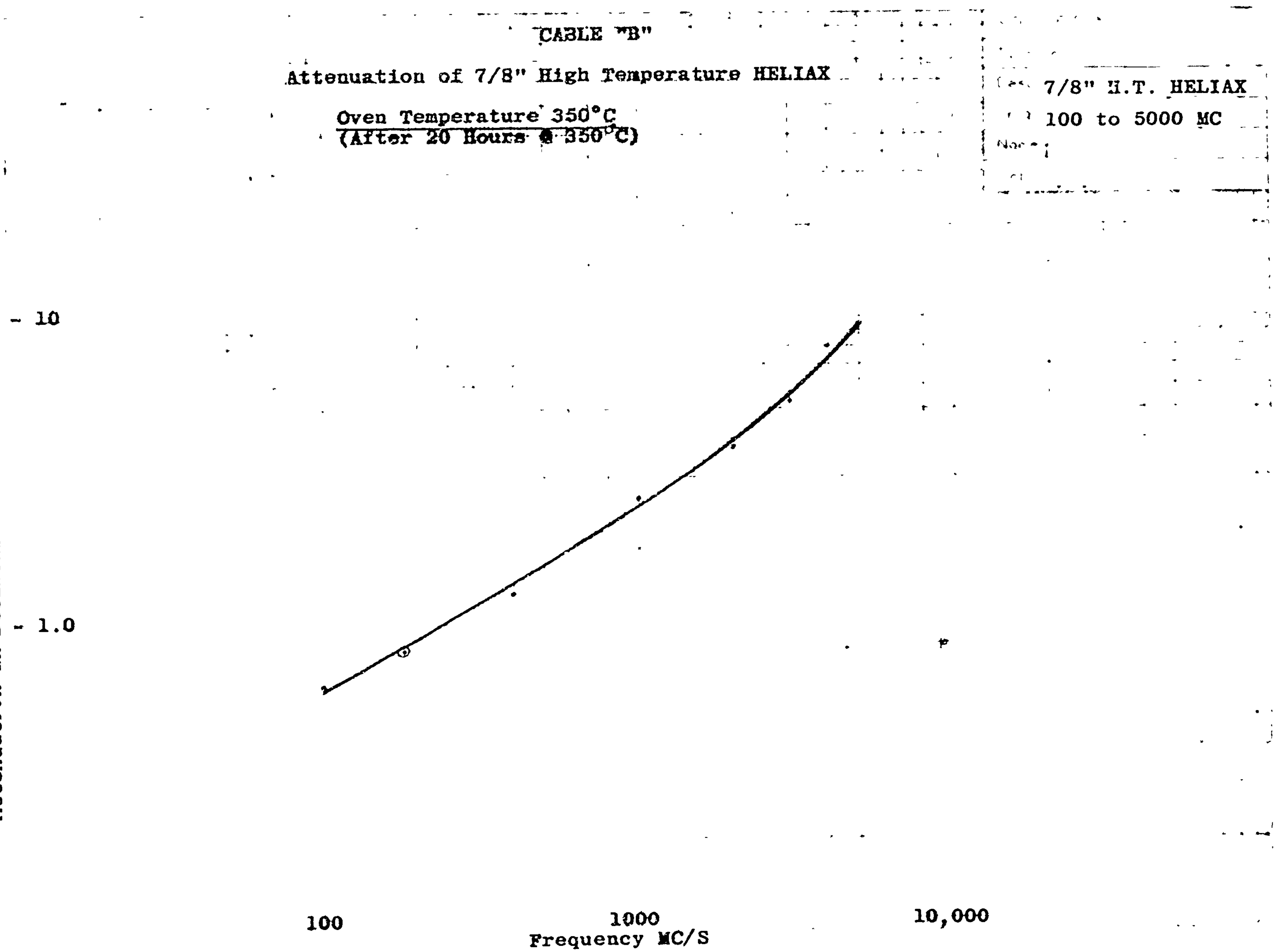

CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Oven Temperature 350°C
(After 20 Hours @ 350°C)
7/8" H.T. HELIAX
100 to 5000 MC
10
1.0
Attenuation in Decibels Per 100 Ft.
100
1000
10,000
Frequency MC/S

Figure 44.

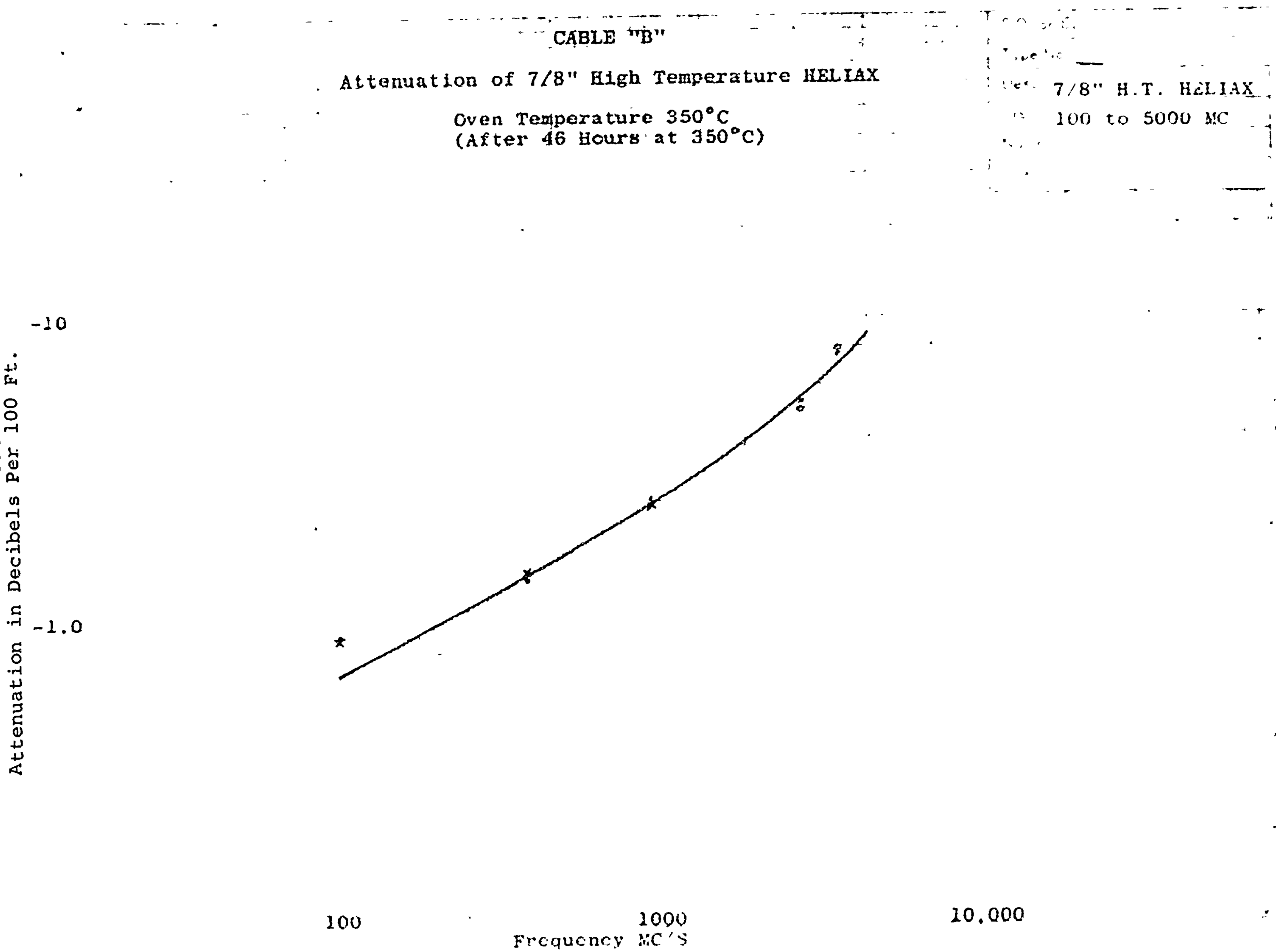

CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Oven Temperature 350°C
(After 46 Hours at 350°C)
7/8" H.T. HELIAX
100 to 5000 MC
-10
-1.0
Attenuation in Decibels Per 100 Ft.
100
1000
10,000
Frequency MC'S

Figure 45.

CABLE "B"

Attenuation of 7/8" High Temperature HELIAX

Oven Temperature 350°C
(After 66 Hours at 350°C)

7/8" H.T. HELIAX
100 to 5000 MC

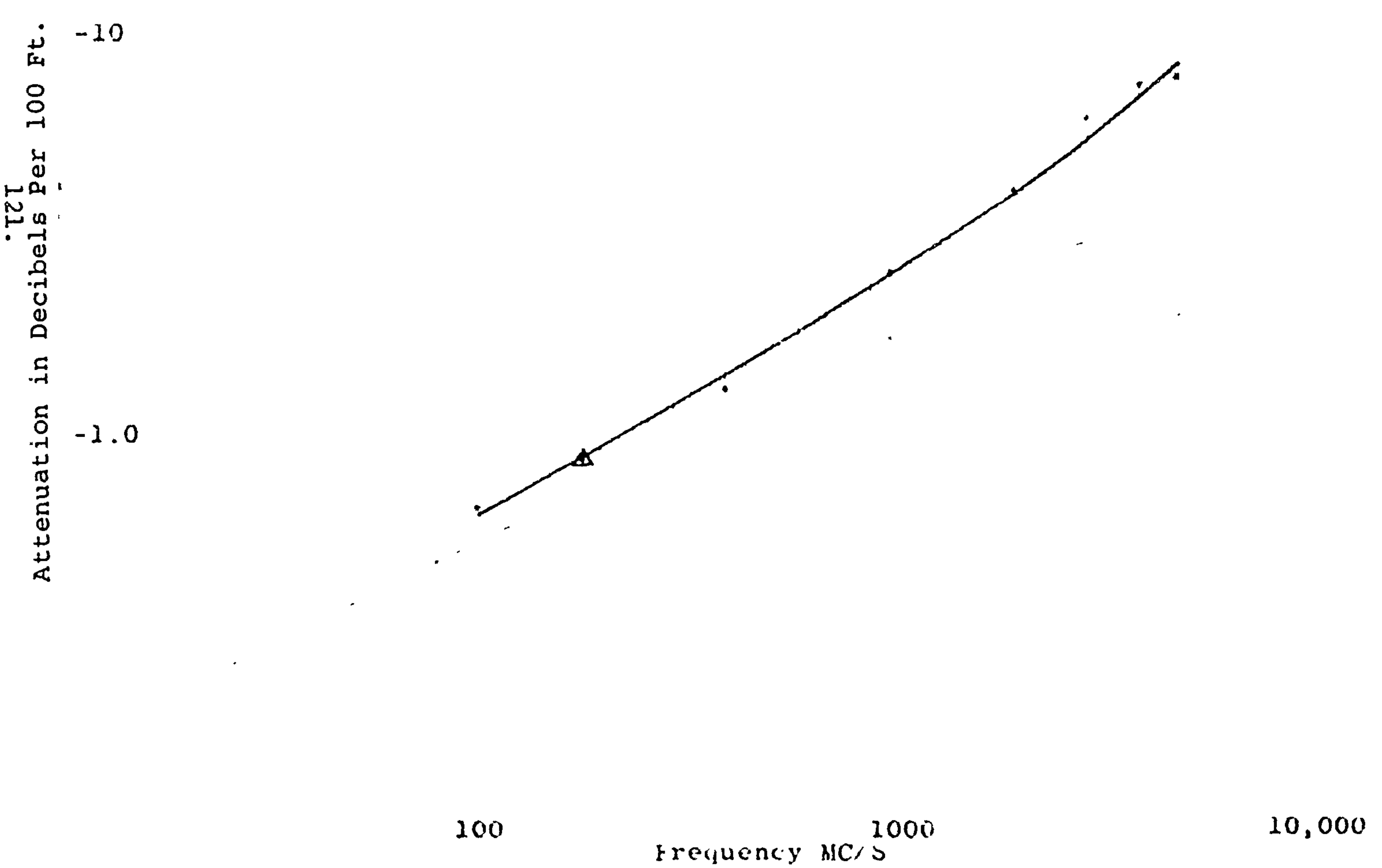
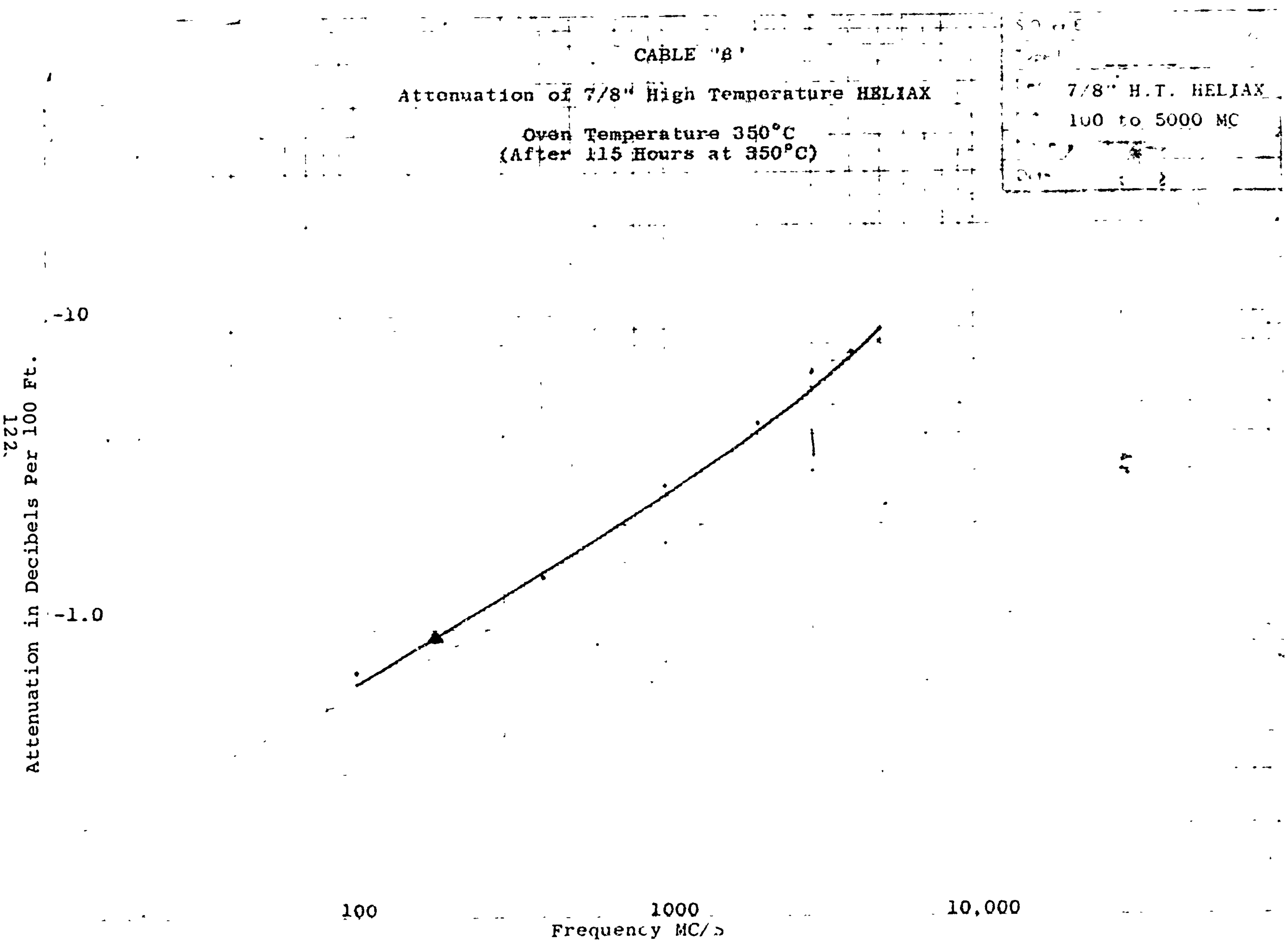


Figure 46.



CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Oven Temperature 350°C
(After 115 Hours at 350°C)
7/8" H.T. HELIAX
100 to 5000 MC
-10
-1.0
Attenuation in Decibels Per 100 Ft.
100
1000
10,000
Frequency MC/s

Figure 47.

Frequency MC/S

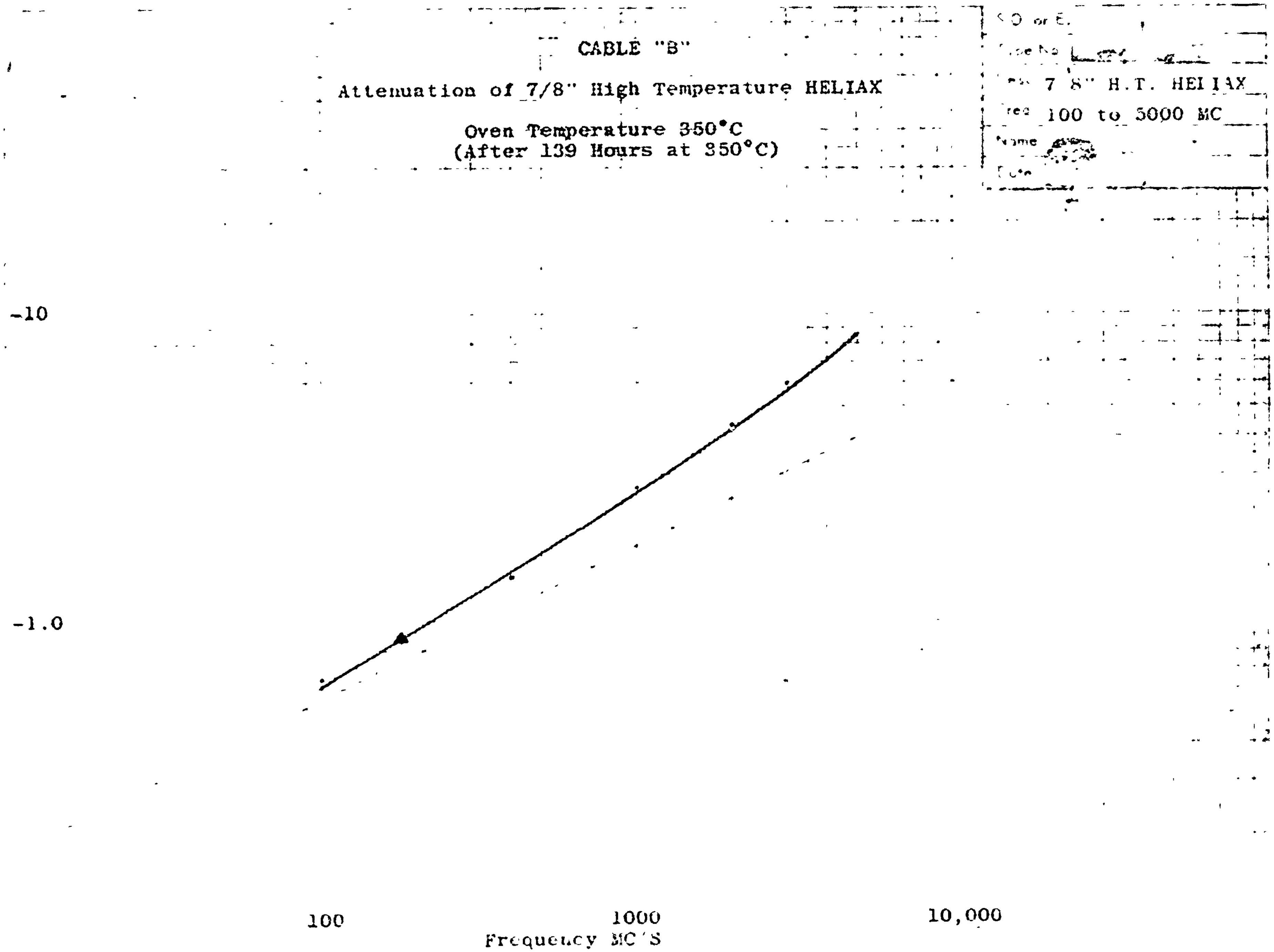


Figure 48.

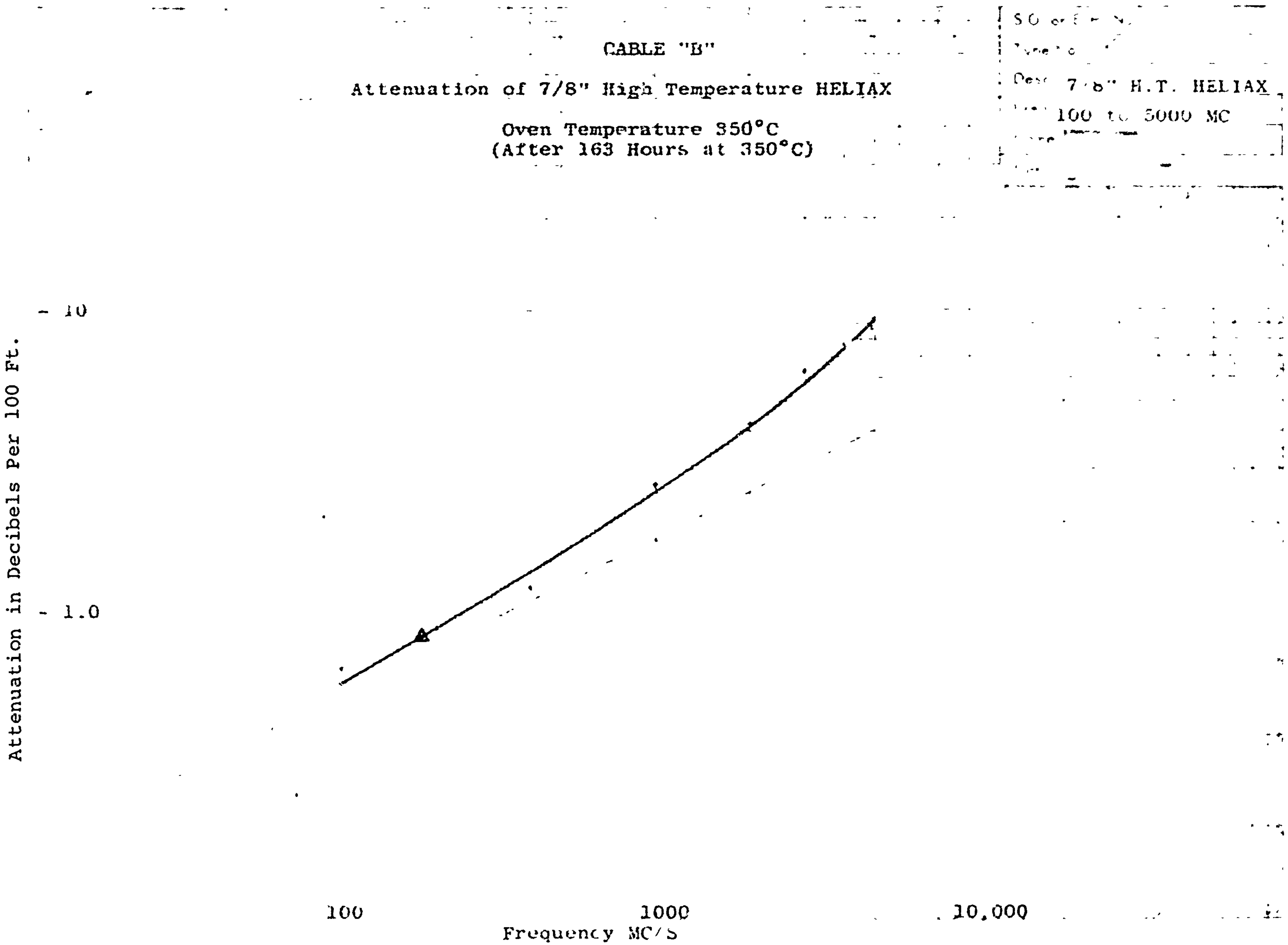
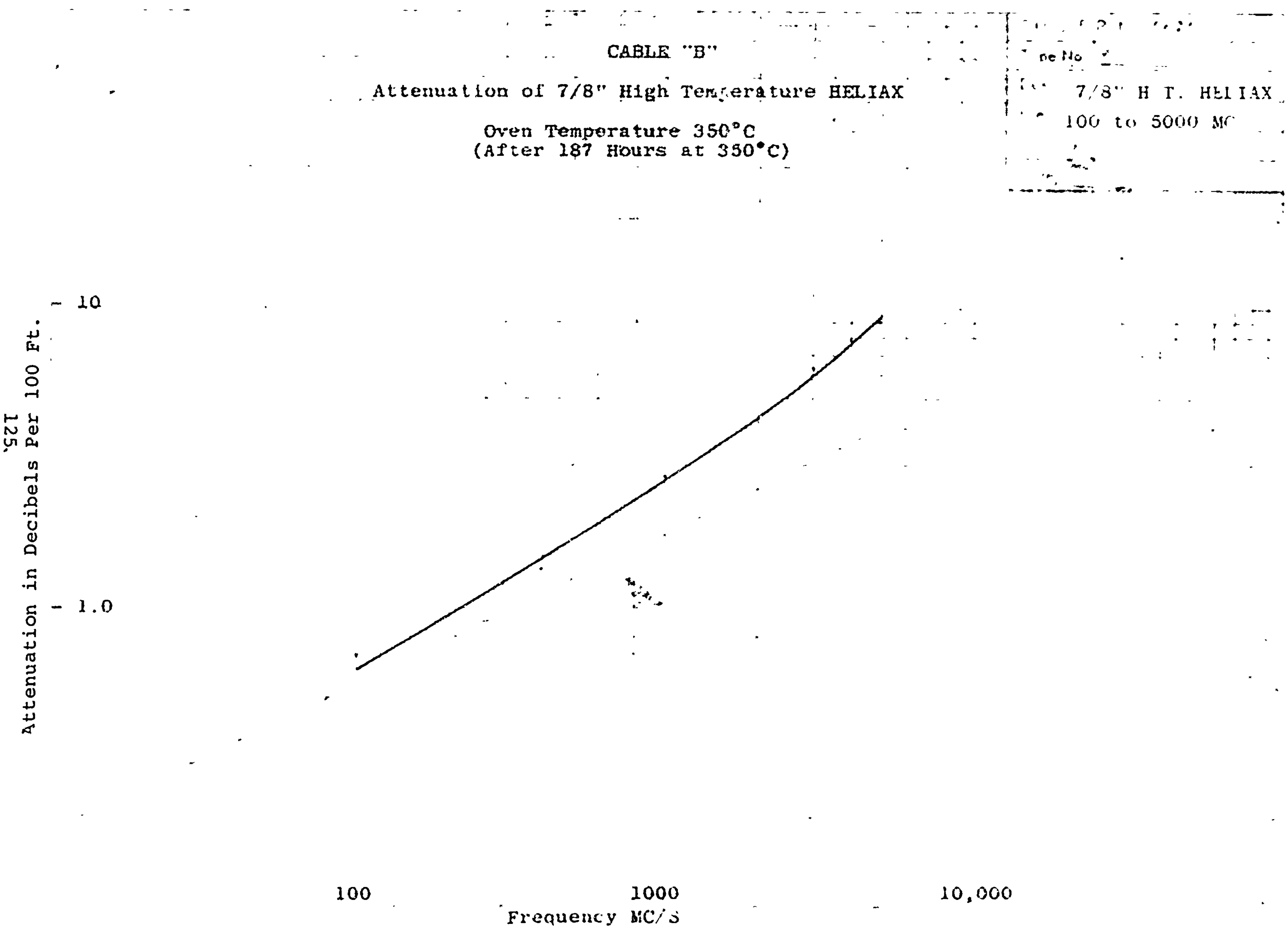

CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Oven Temperature 350°C
(After 163 Hours at 350°C)
7/8" H.T. HELIAX
100 to 5000 MC
10
1.0
Attenuation in Decibels Per 100 Ft.
100
1000
10,000
Frequency MC/S

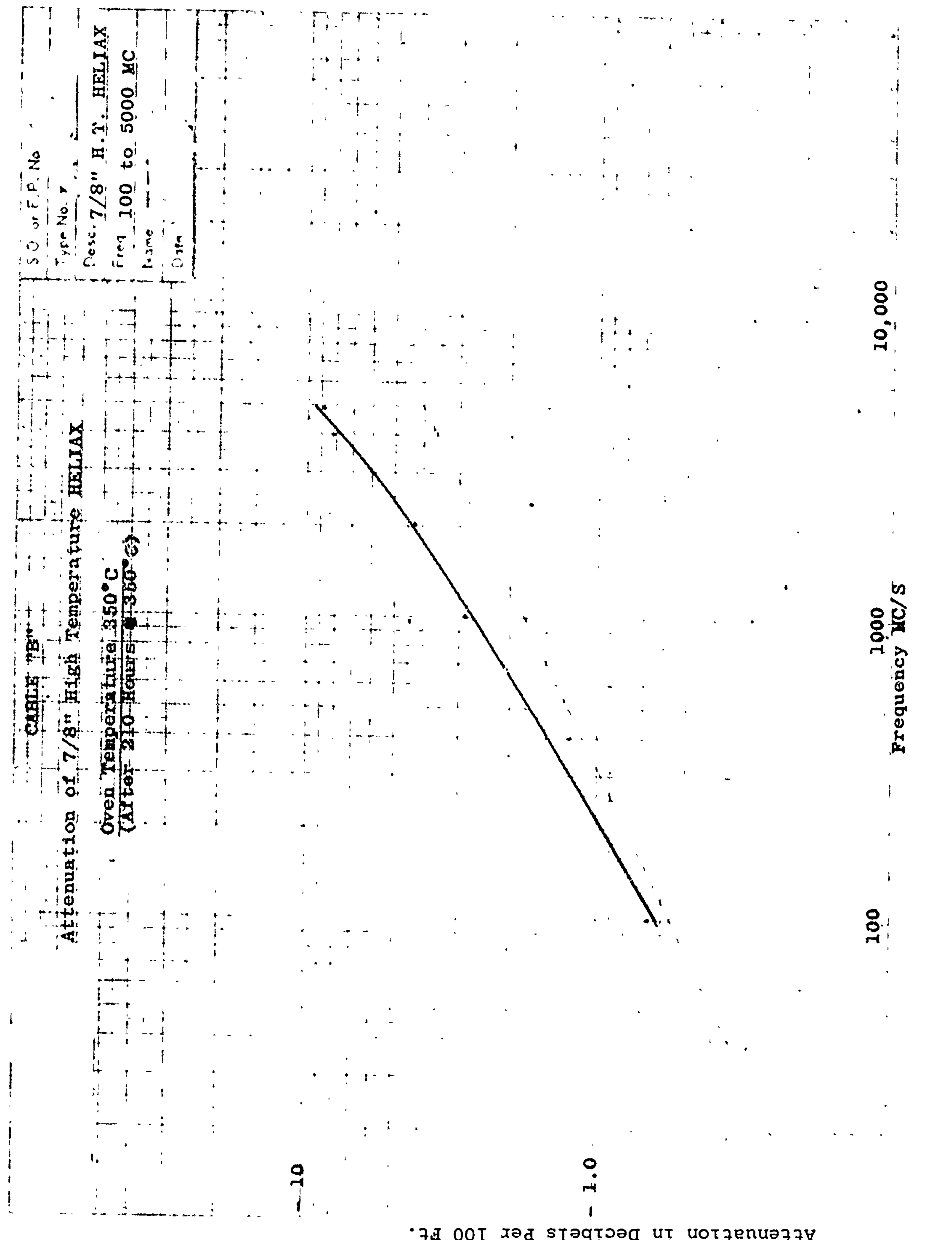
Figure 49.



CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Oven Temperature 350°C
(After 187 Hours at 350°C)
7/8" H T. HELIAX
100 to 5000 MC
Attenuation in Decibels Per 100 Ft.
10
1.0
100
1000
10,000
Frequency MC/S

Figure 50.

Figure 51.



CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Oven Temperature 350°C
(After 210 Hours @ 350°C)
S.O. or F.P. No.
Type No.
Desc. 7/8" H.T. HELIAX
Freq 100 to 5000 MC
Name
Date
10
1.0
100
1000
10,000
Frequency MC/S
Attenuation in Decibels Per 100 Ft.

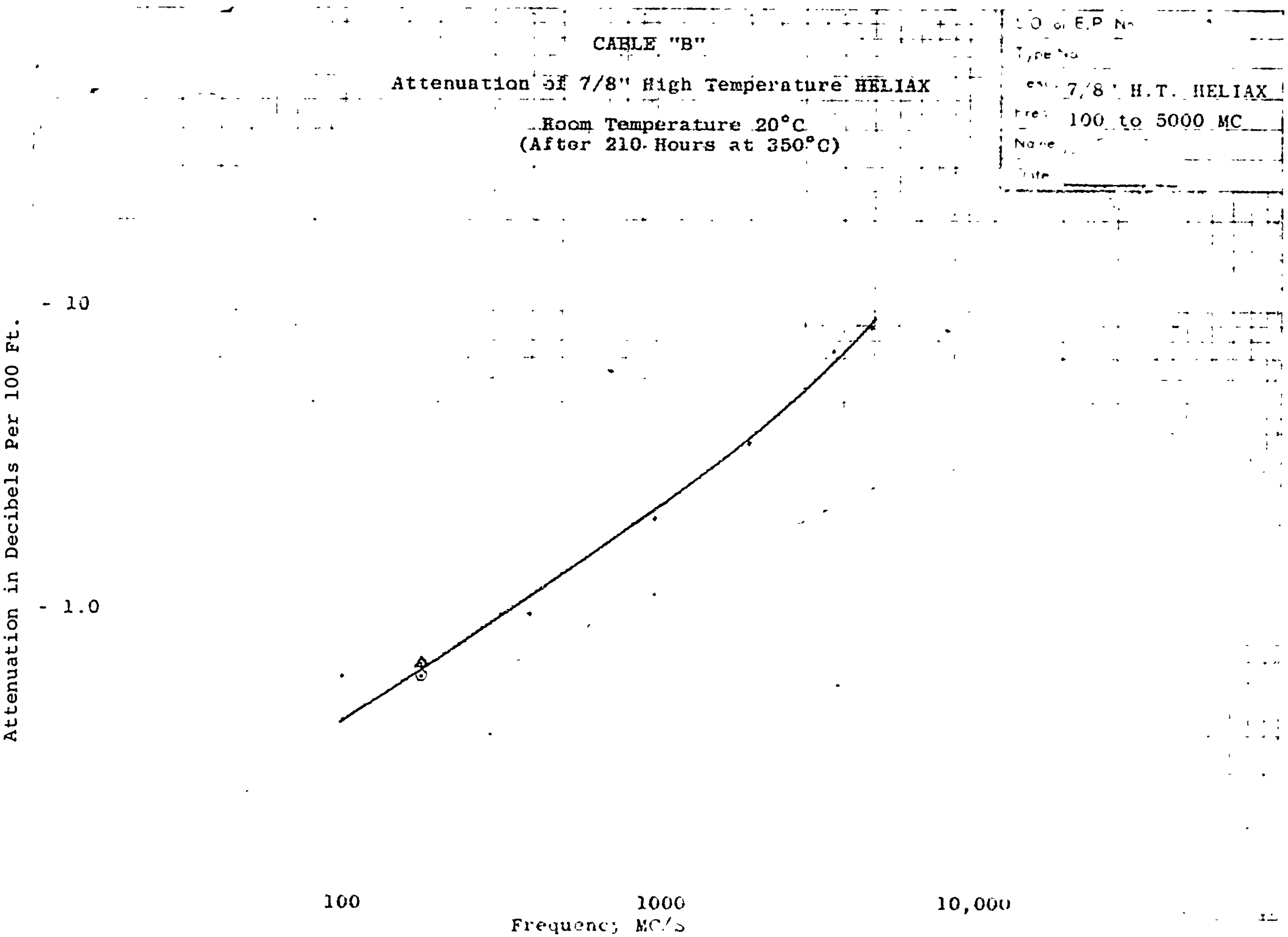

CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Room Temperature 20°C
(After 210 Hours at 350°C)
7/8" H.T. HELIAX
100 to 5000 MC
10
1.0
Attenuation in Decibels Per 100 Ft.
100
1000
10,000
Frequency MC/S

Figure 52.

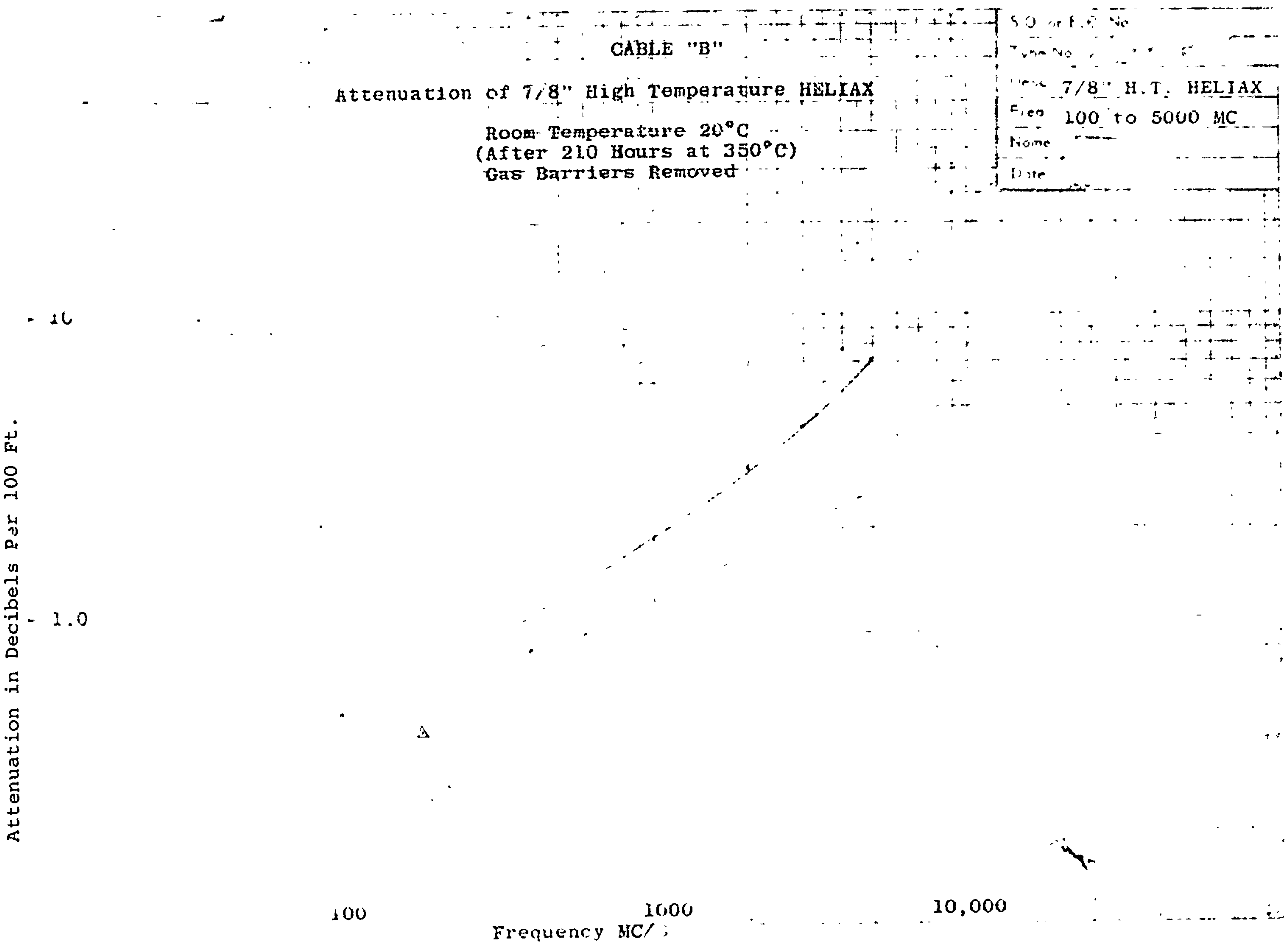

CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Room Temperature 20°C
(After 210 Hours at 350°C)
Gas Barriers Removed
7/8" H.T. HELIAX
100 to 5000 MC
Name
Date
Attenuation in Decibels Per 100 Ft.
10
1.0
100
1000
10,000
Frequency MC/

Figure 53.

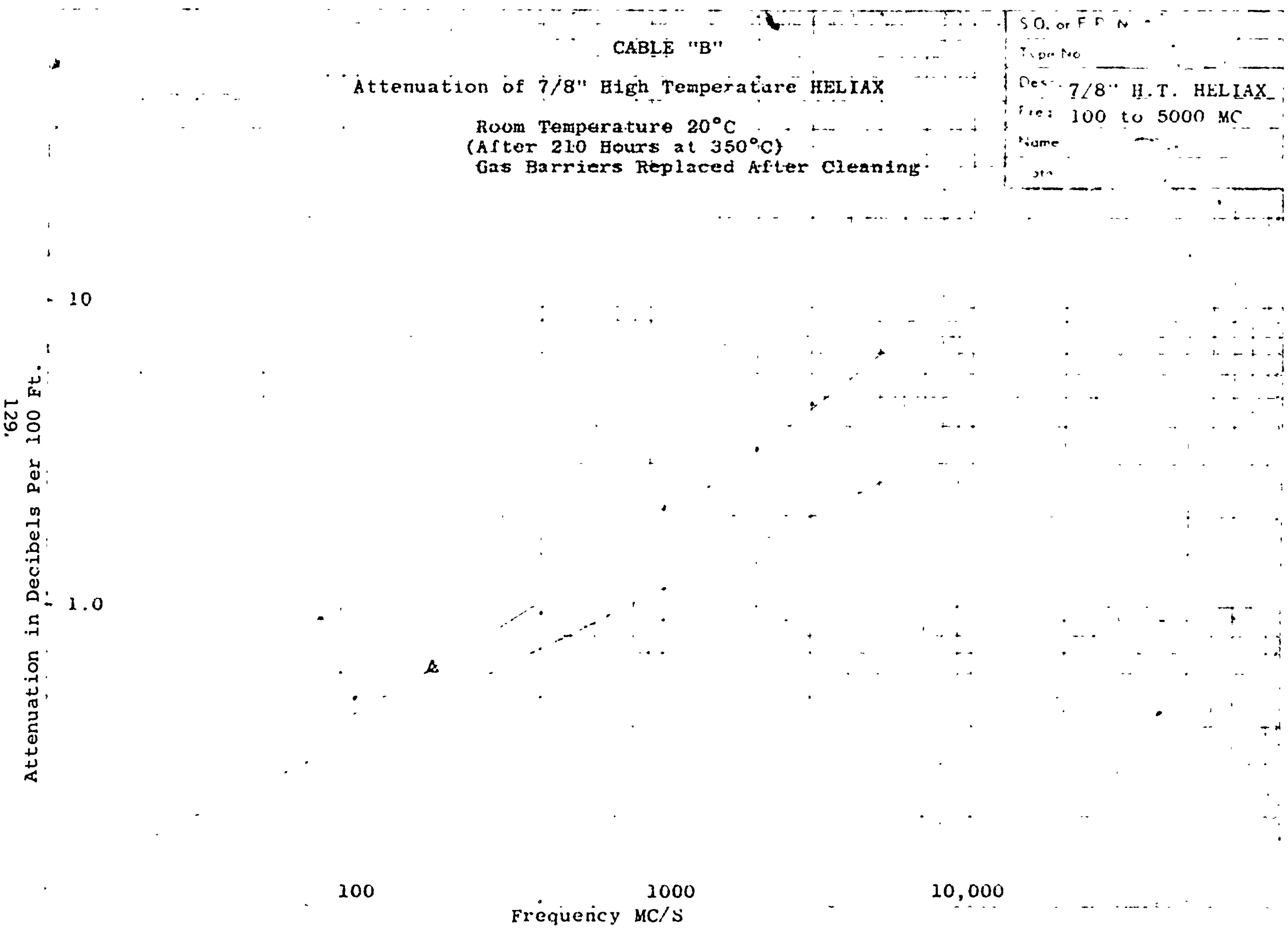

CABLE "B"
Attenuation of 7/8" High Temperature HELIAX
Room Temperature 20°C
(After 210 Hours at 350°C)
Gas Barriers Replaced After Cleaning
S.O. or F.P. N
Type No
Des 7/8" H.T. HELIAX
Freq 100 to 5000 MC
Name
10
1.0
Attenuation in Decibels Per 100 Ft.
100
1000
10,000
Frequency MC/S

Figure 54.

CABLE "B"

Attenuation of 7/8" High Temperature HELIAX

Cold Chamber Temperature -65°C

7/8" H T HELIAX
100 to 5000 MC

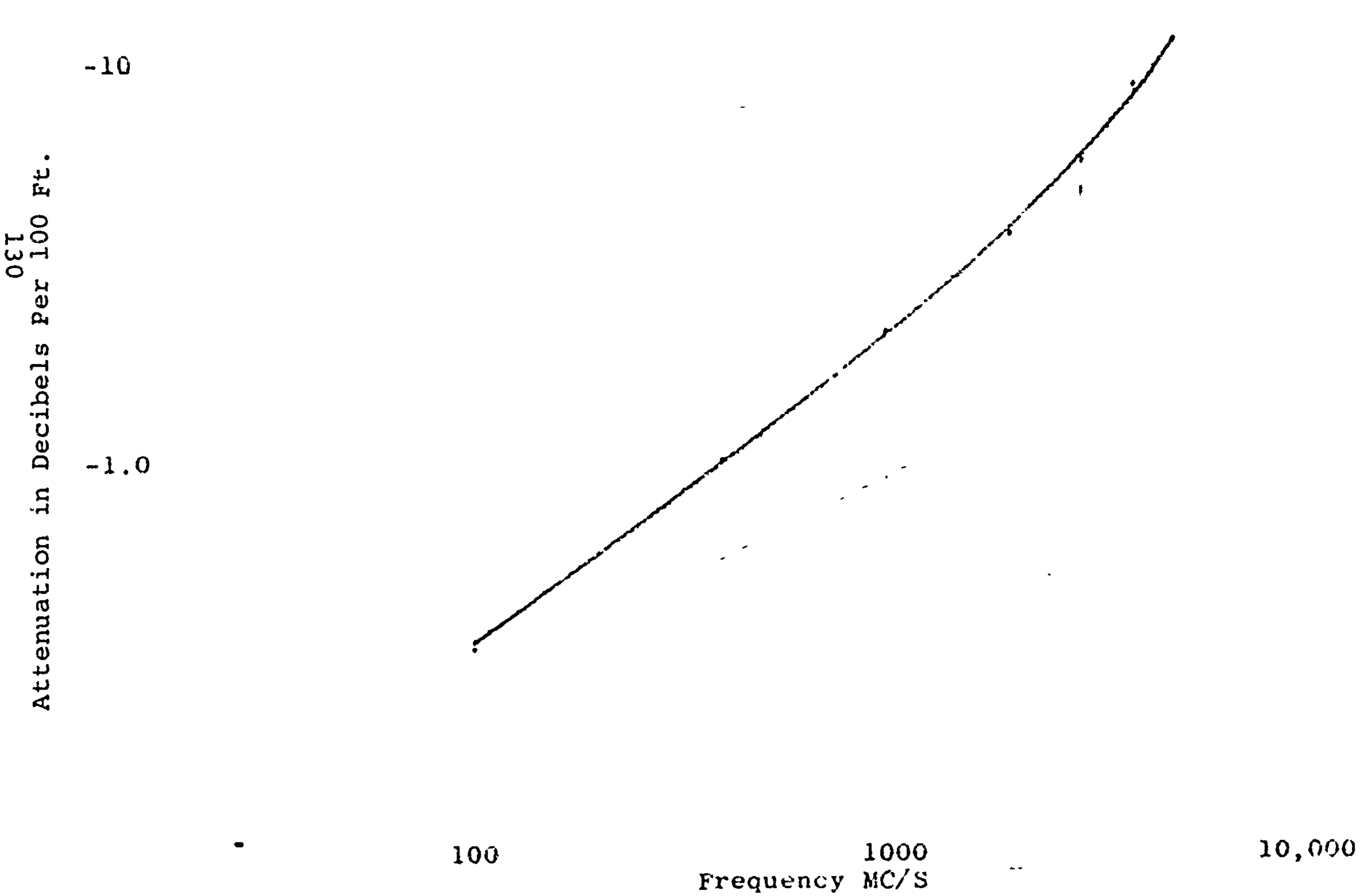


Figure 55.

Figure 55 a.

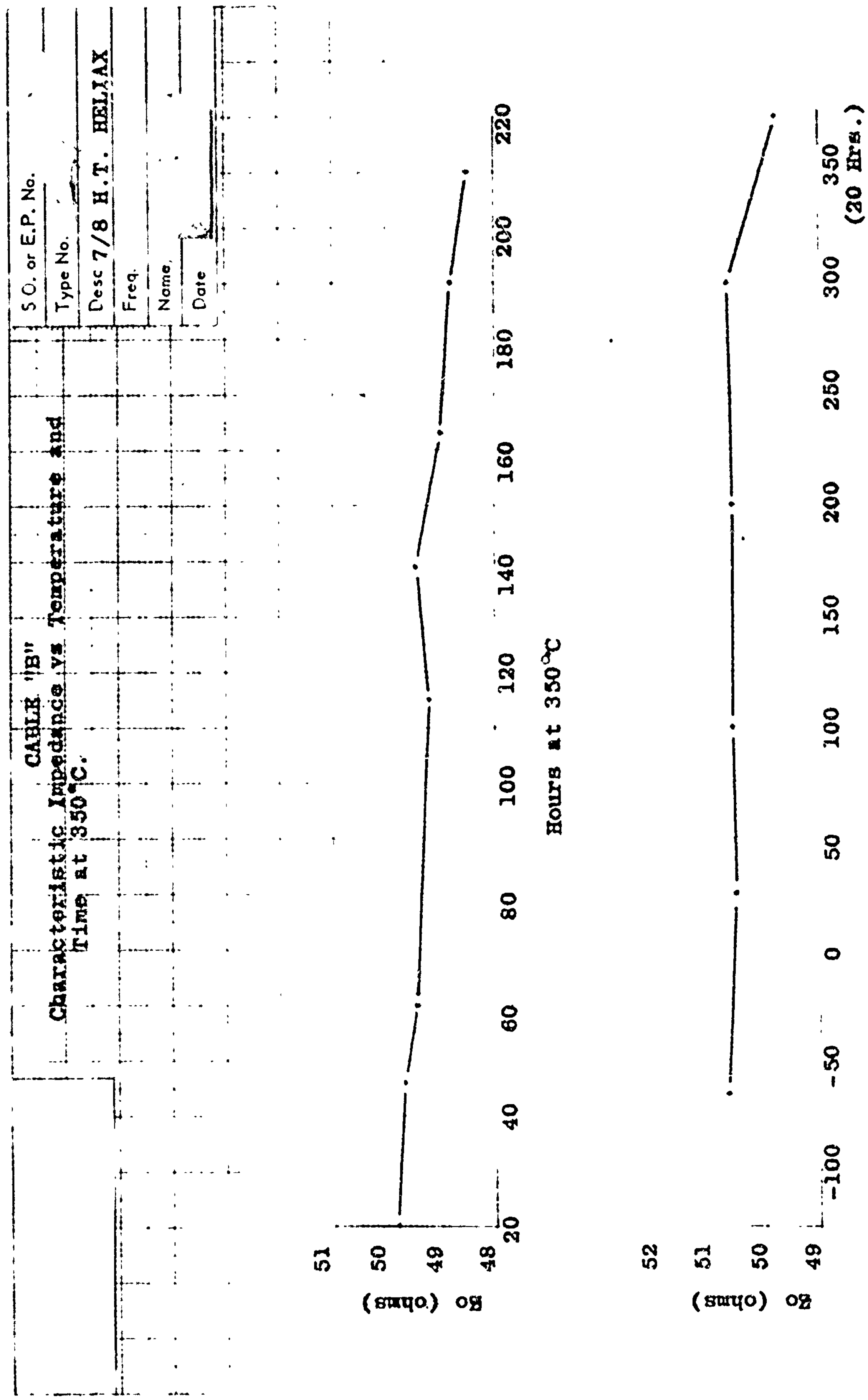

CABLE "B"
Characteristic Impedance vs Temperature and Time at 350°C.
S.O. or E.P. No.
Type No.
Desc 7/8 H.T. HELIAX
Freq.
Name
Date
Zo (ohms)
51
50
49
48
20
40
60
80
100
120
140
160
180
200
220
Hours at 350°C
Zo (ohms)
52
51
50
49
-100
-50
0
50
100
150
200
250
300
350
(20 Hrs.)
TEMPERATURE - °C

Figure 56.

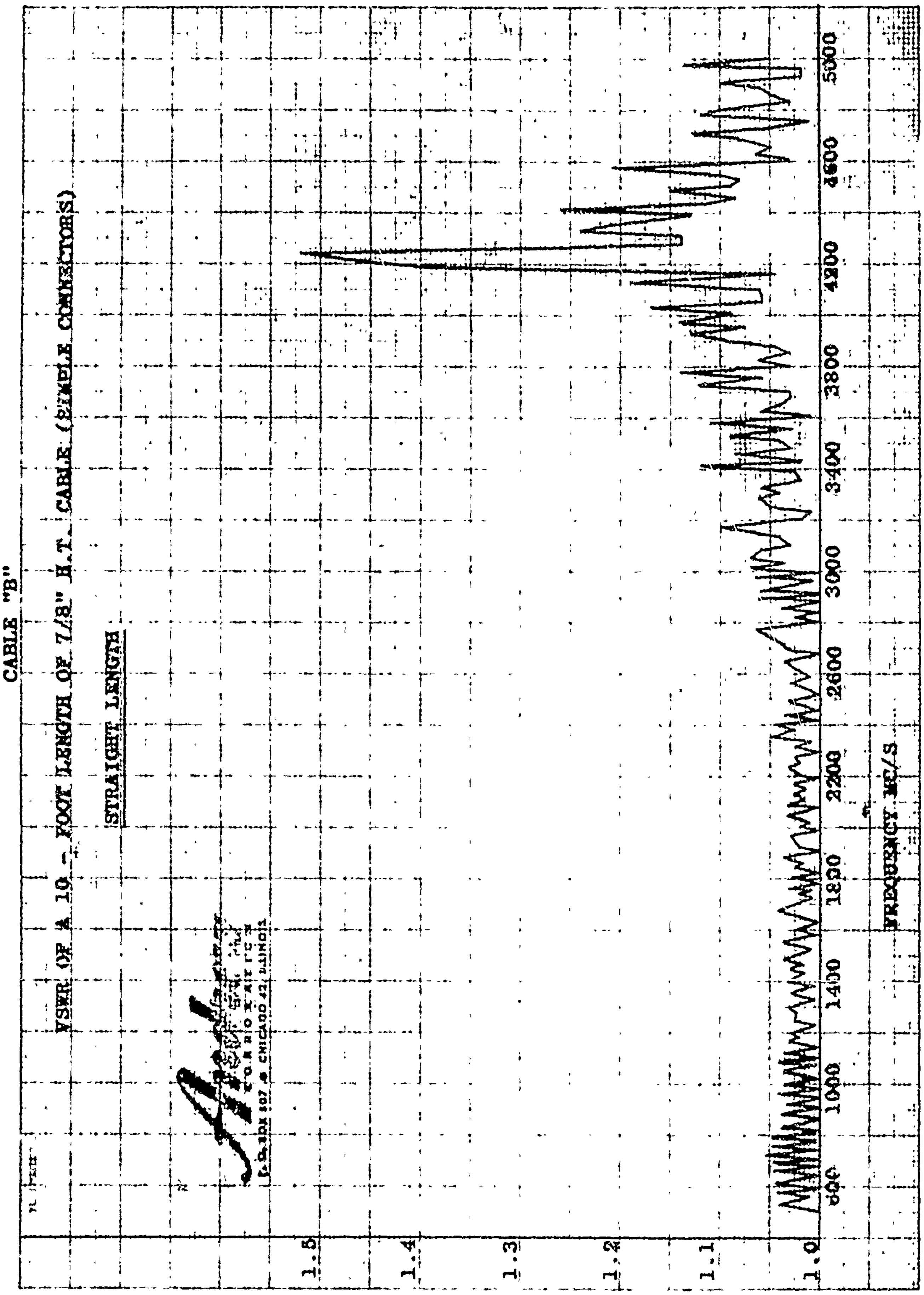

CABLE "B"
VSWR OF A 10 - FOOT LENGTH OF 7/8" H.T. CABLE (SAMPLE CONNECTORS)
STRAIGHT LENGTH
600
1000
1400
1800
2200
2600
3000
3400
3800
4200
4600
5000
FREQUENCY MC/S
1.0
1.1
1.2
1.3
1.4
1.5
VSWR

Figure 57.

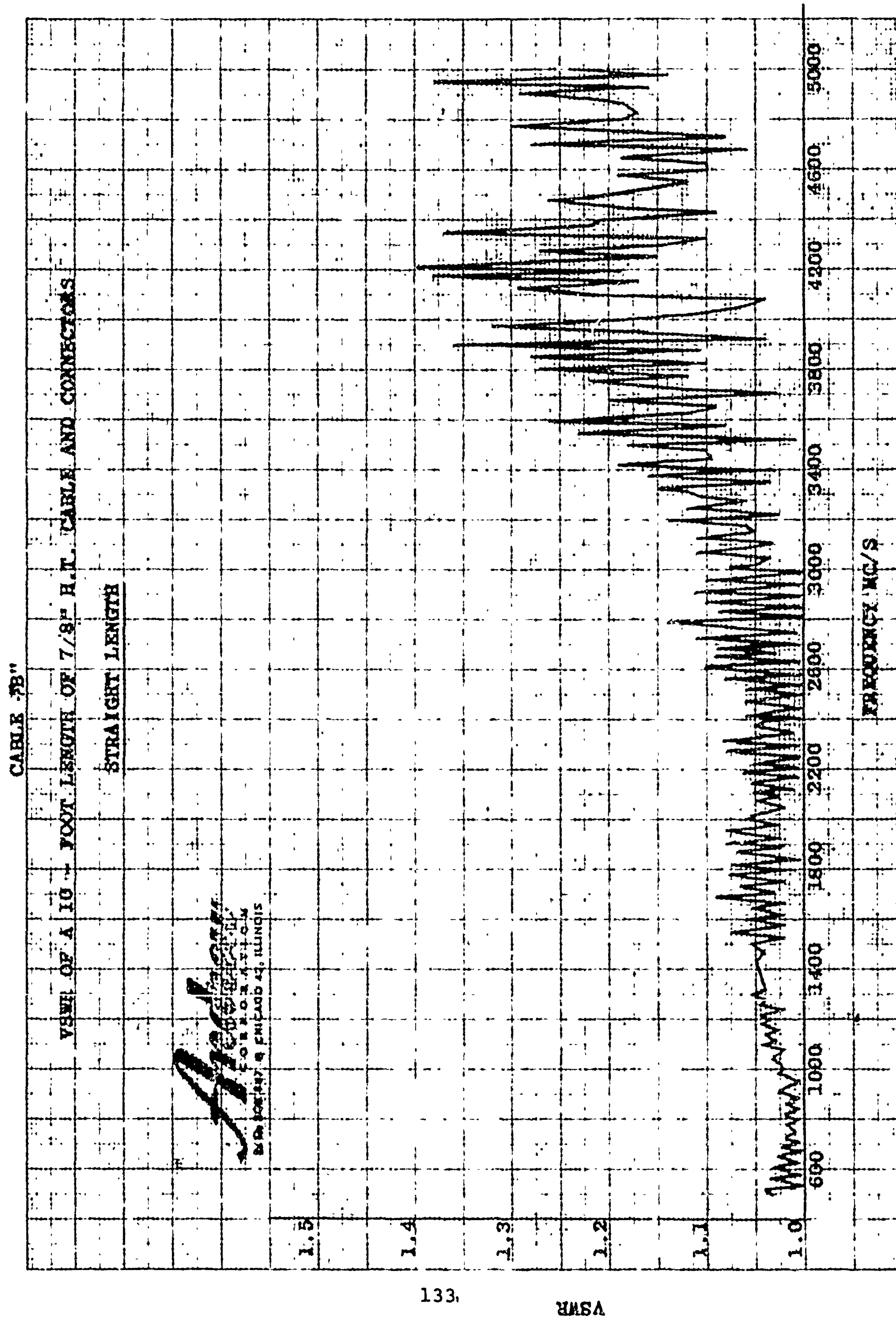
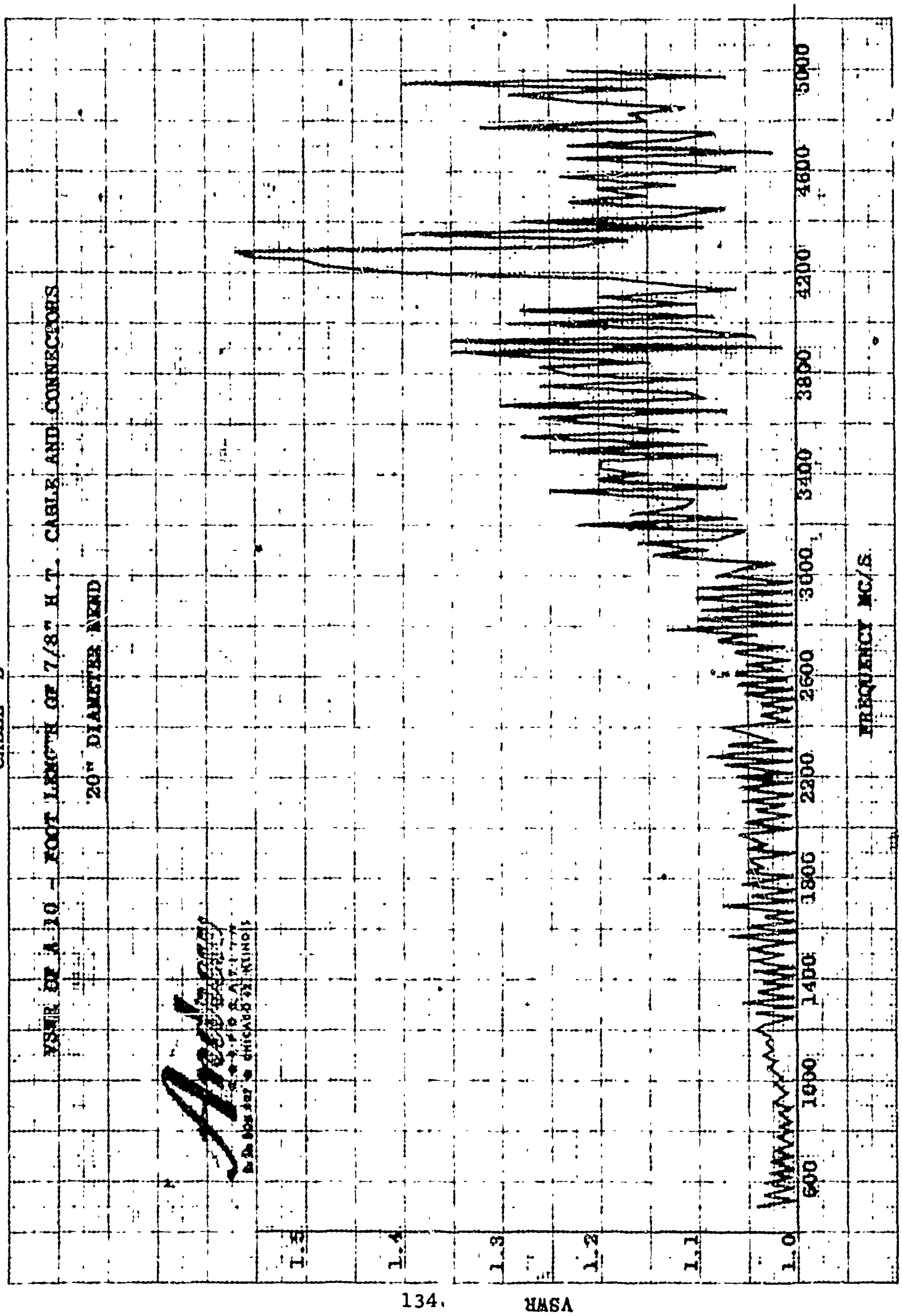

CABLE "B"
VSWR OF A 10 - FOOT LENGTH OF 7/8" H.T. CABLE AND CONNECTORS
STRAIGHT LENGTH
FREQUENCY MC/S
600 1000 1400 1800 2200 2600 3000 3400 3800 4200 4600 5000
1.0 1.1 1.2 1.3 1.4 1.5
VSWR

Figure 58.



CABLE "B"
VSWR OF A 10 - FOOT LENGTH OF 7/8" H.T. CABLE AND CONNECTORS
20" DIAMETER BEND
FREQUENCY MC/S
600
1000
1400
1800
2200
2600
3000
3400
3800
4200
4600
5000
1.0
1.1
1.2
1.3
1.4
1.5
VSWR

Figure 59.

CABLE "B"

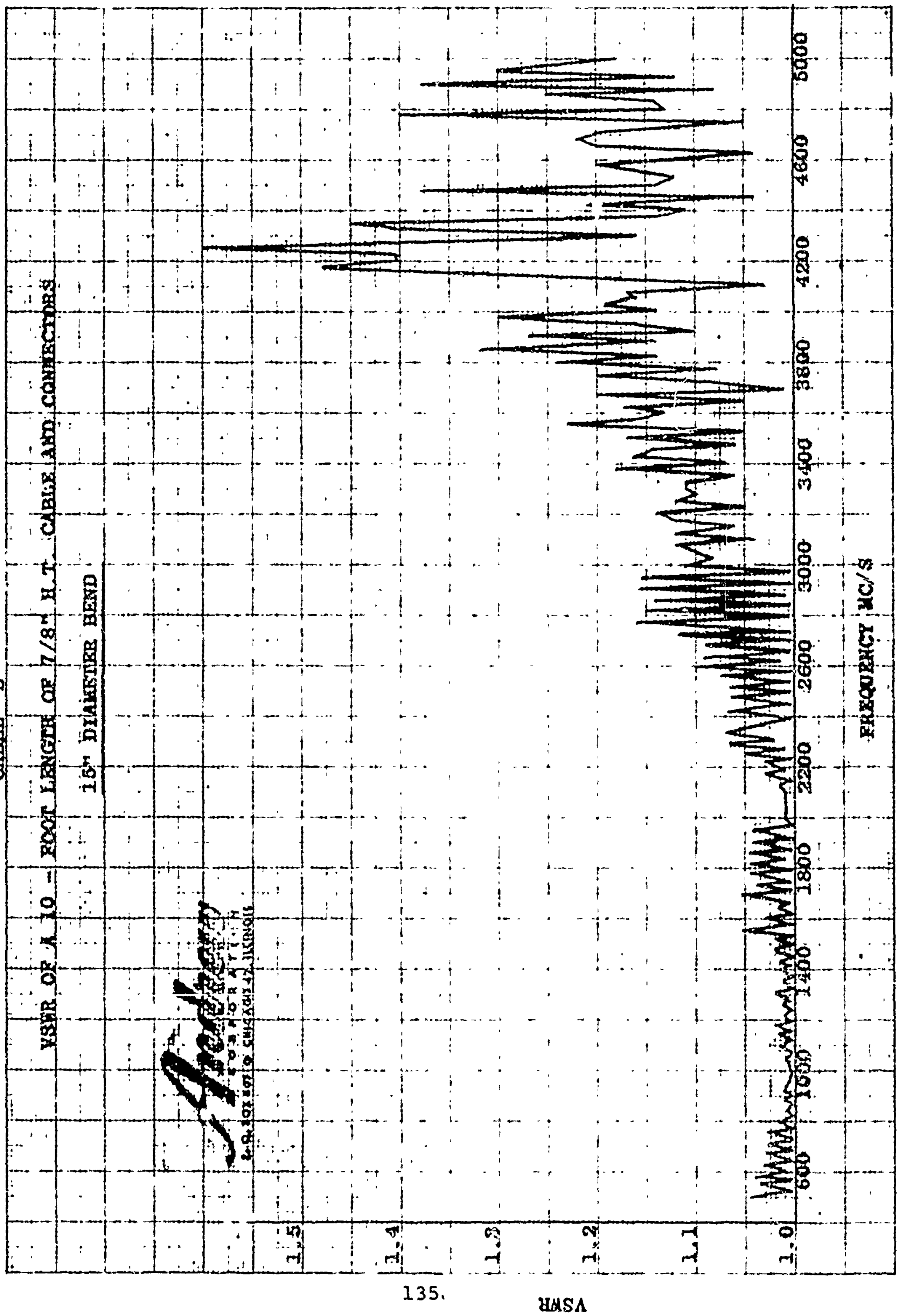


Figure 60

CABLE "B"

VSWR OF A 10 - FOOT LENGTH OF 7/8" H.T. CABLE AND CONNECTORS

13" DIAMETER BEND

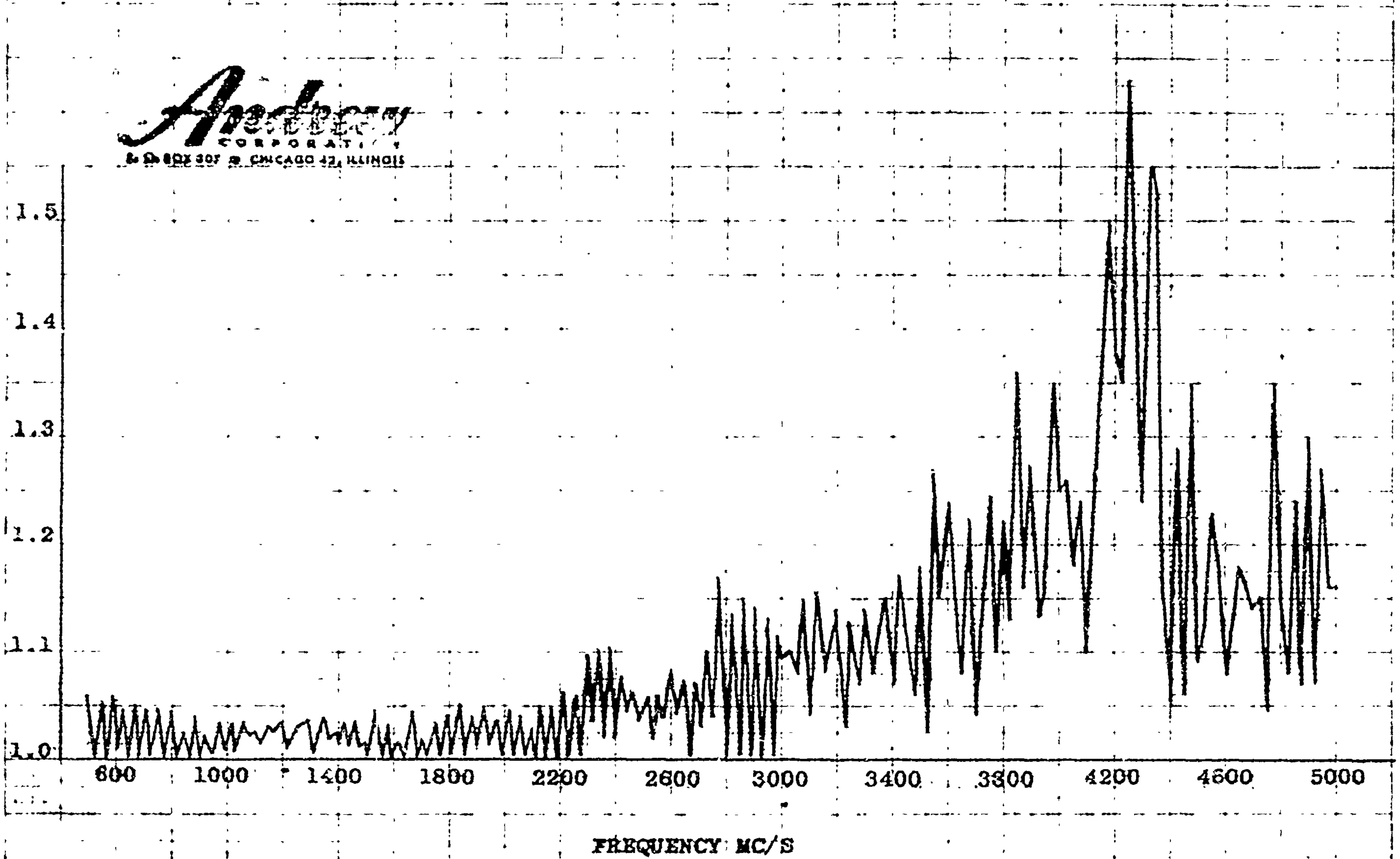


Figure 61.

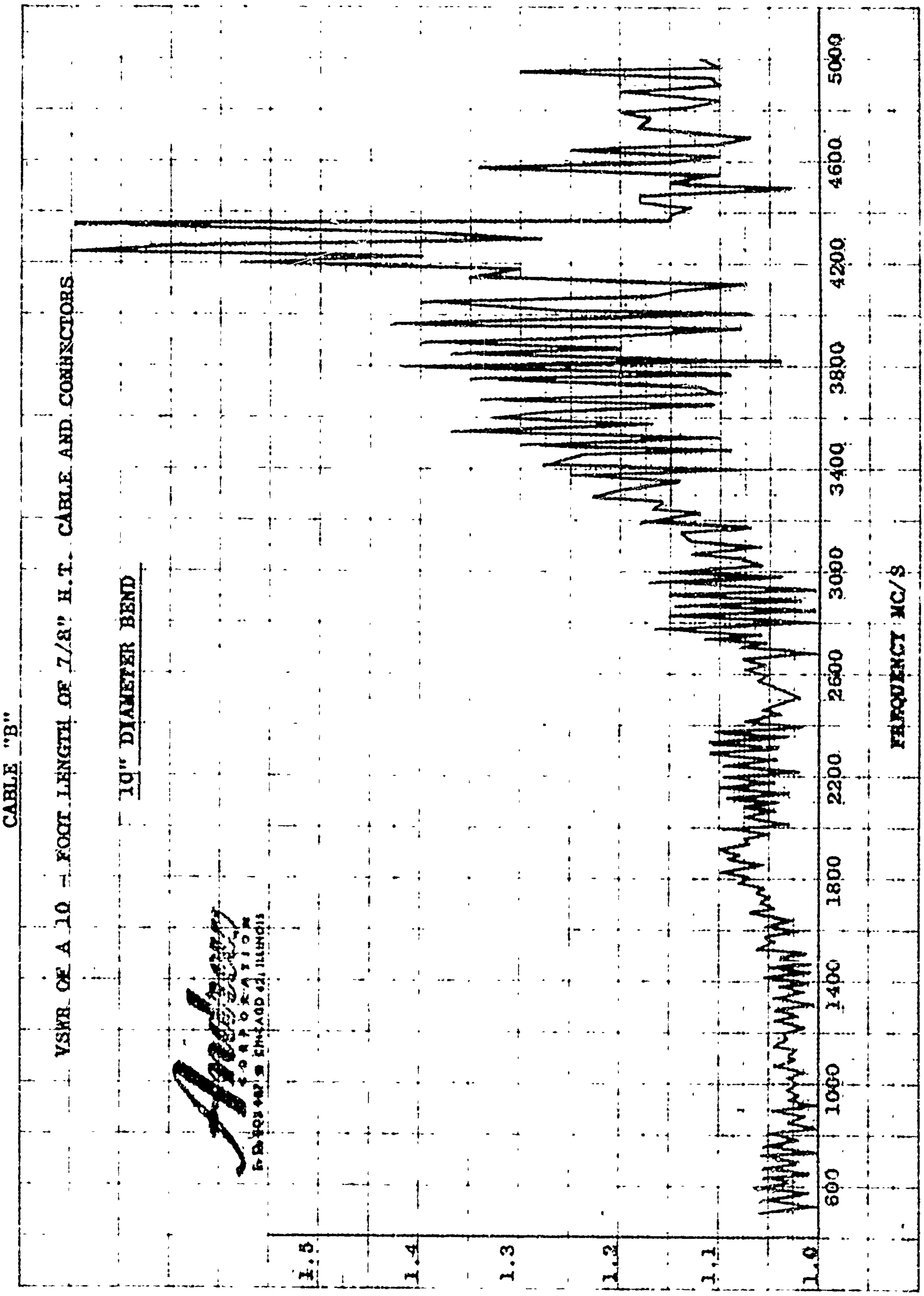

CABLE "B"
VSWR OF A 10 - FOOT LENGTH OF 7/8" H.T. CABLE AND CONNECTORS
10" DIAMETER BEND
FREQUENCY MC/S
600
1000
1400
1800
2200
2600
3000
3400
3800
4200
4600
5000
1.0
1.1
1.2
1.3
1.4
1.5
VSWR

Figure 62.

CABLE "B"

VSWR OF A 10 - FOOT LENGTH OF 7/8" H.T. CABLE AND CONNECTORS

7" DIAMETER BEND

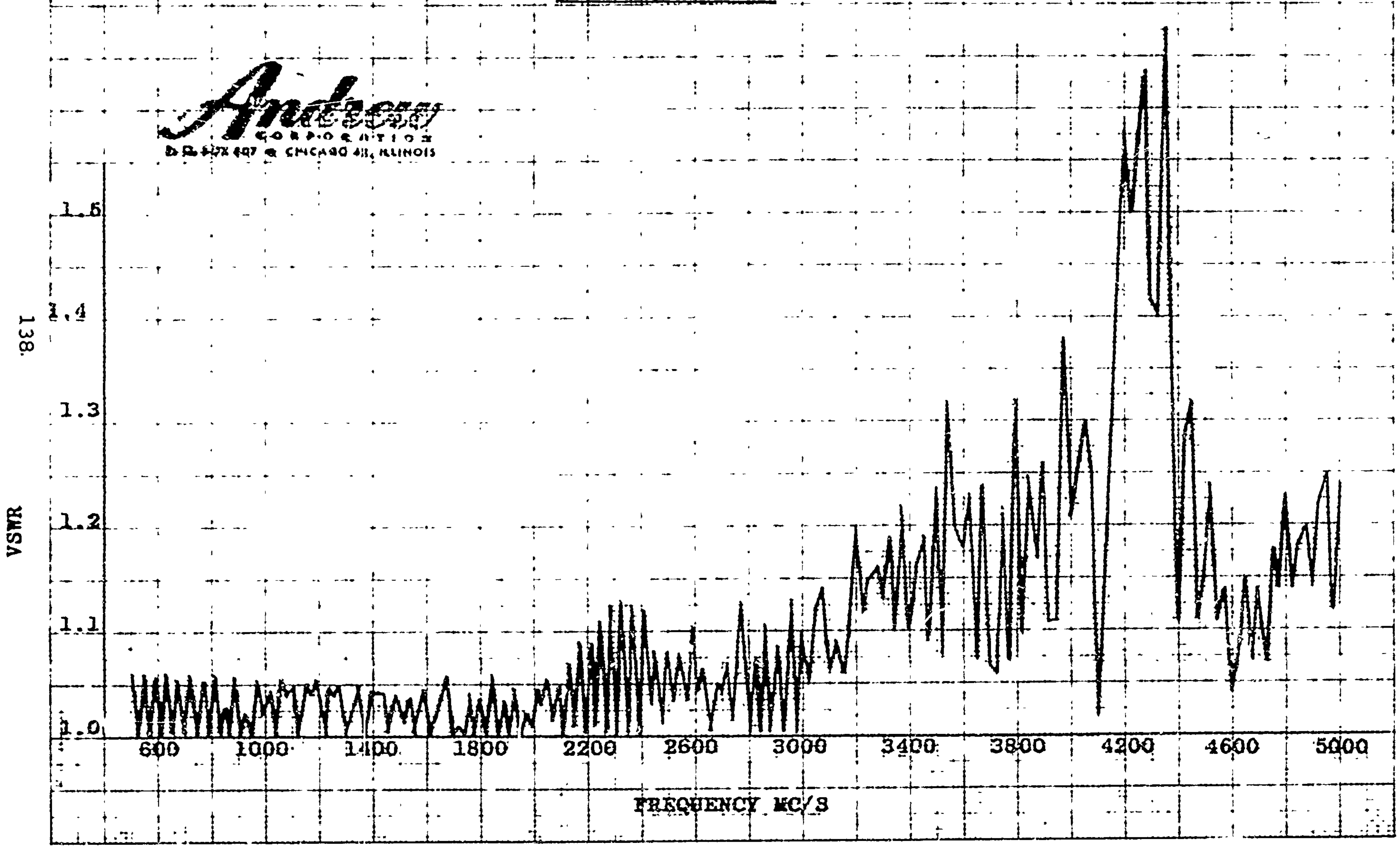
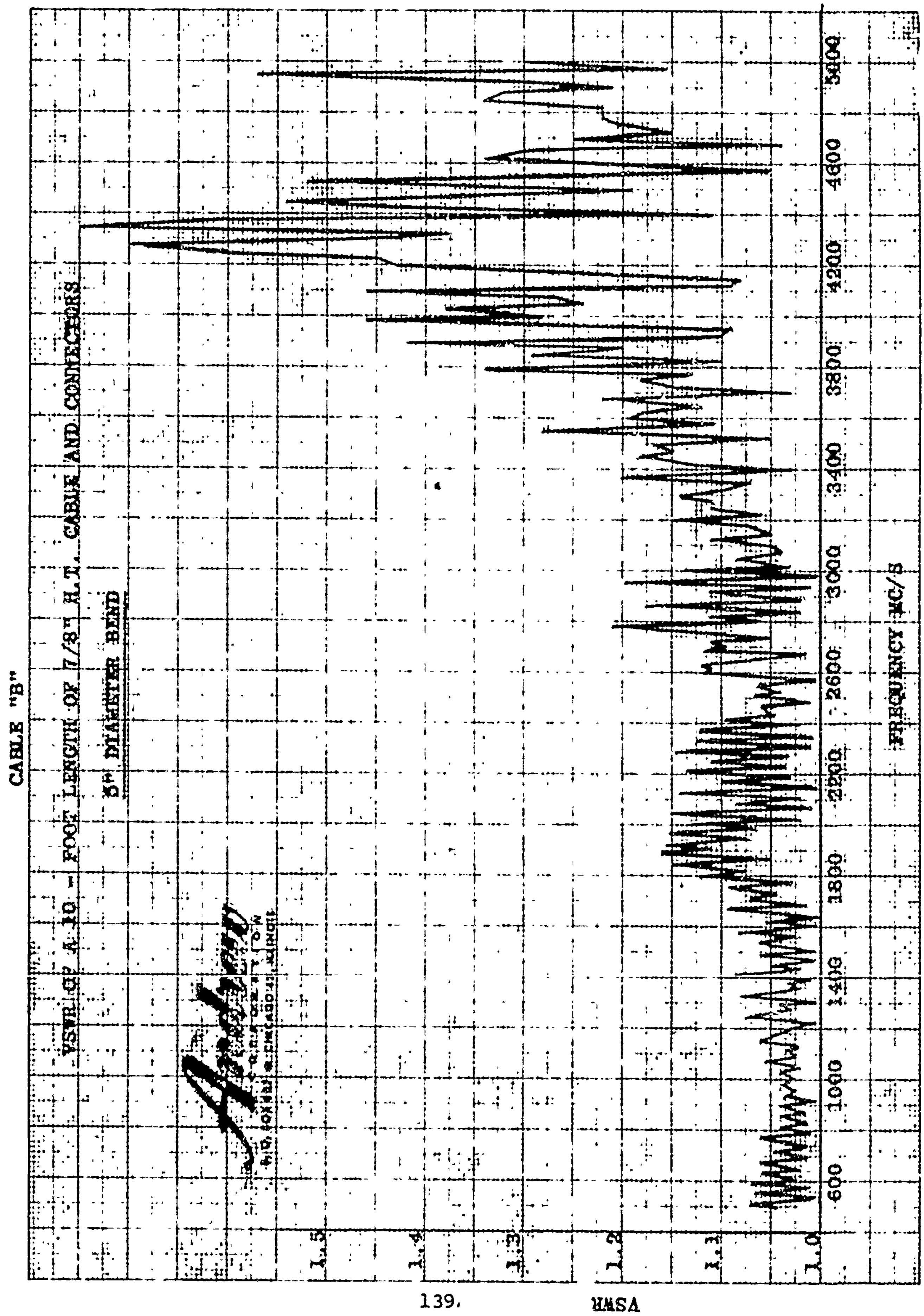


Figure 63.


CABLE "B"
VSWR OF A 10 - FOOT LENGTH OF 7/8" H.T. CABLE AND CONNECTORS
5" DIAMETER BEND
1.5
1.4
1.3
1.2
1.1
1.0
600
1000
1400
1800
2200
2600
3000
3400
3800
4200
4600
5000
FREQUENCY MC/S
VSWR

CABLE "B"

VSWR of a 5 Foot Length of 7/8" H.T. HELIAX
with Gas Barrier - Bent on a 20" diameter
(See Test Procedure Par. 4.5.2)

7/8" H.T. HELIAX
600 - 3000 MC

VSWR before Thermal Shock
(Cable No. 1)

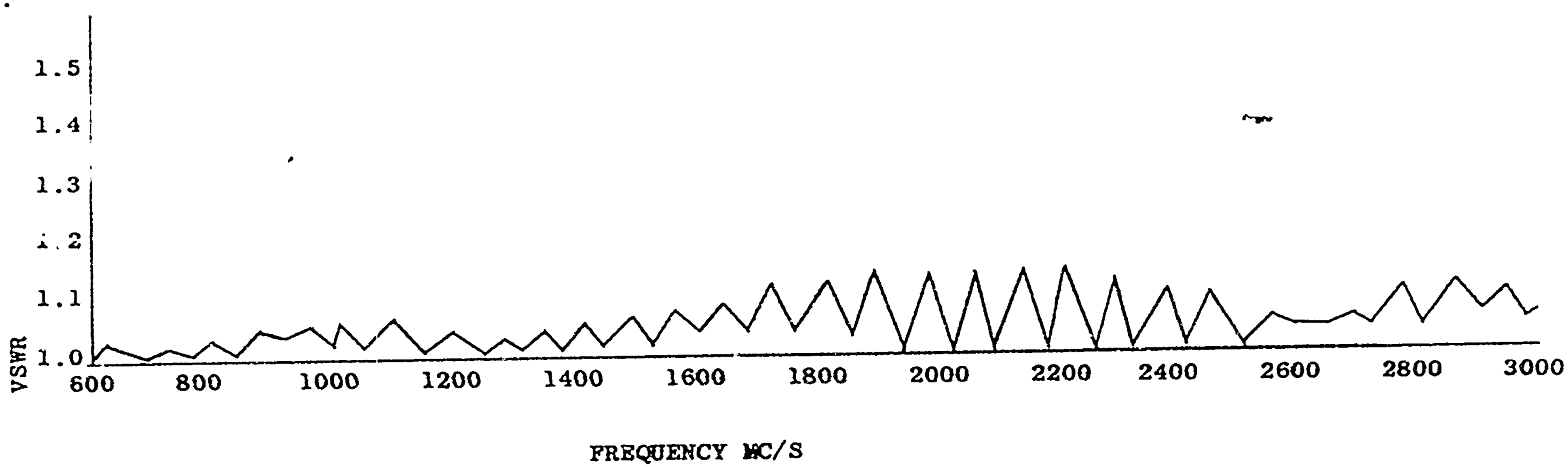


Figure 64.

CABLE "B"

VSWR of a 5 Foot length of 7/8" H.T. HELIAX with Gas Barrier - Bent on a 20" diameter (See Test Procedure Par. 4.5.2)

VSWR before thermal shock
(Cable No. 1)

7/8" H.T. HELIAX
3000 - 5000 MC

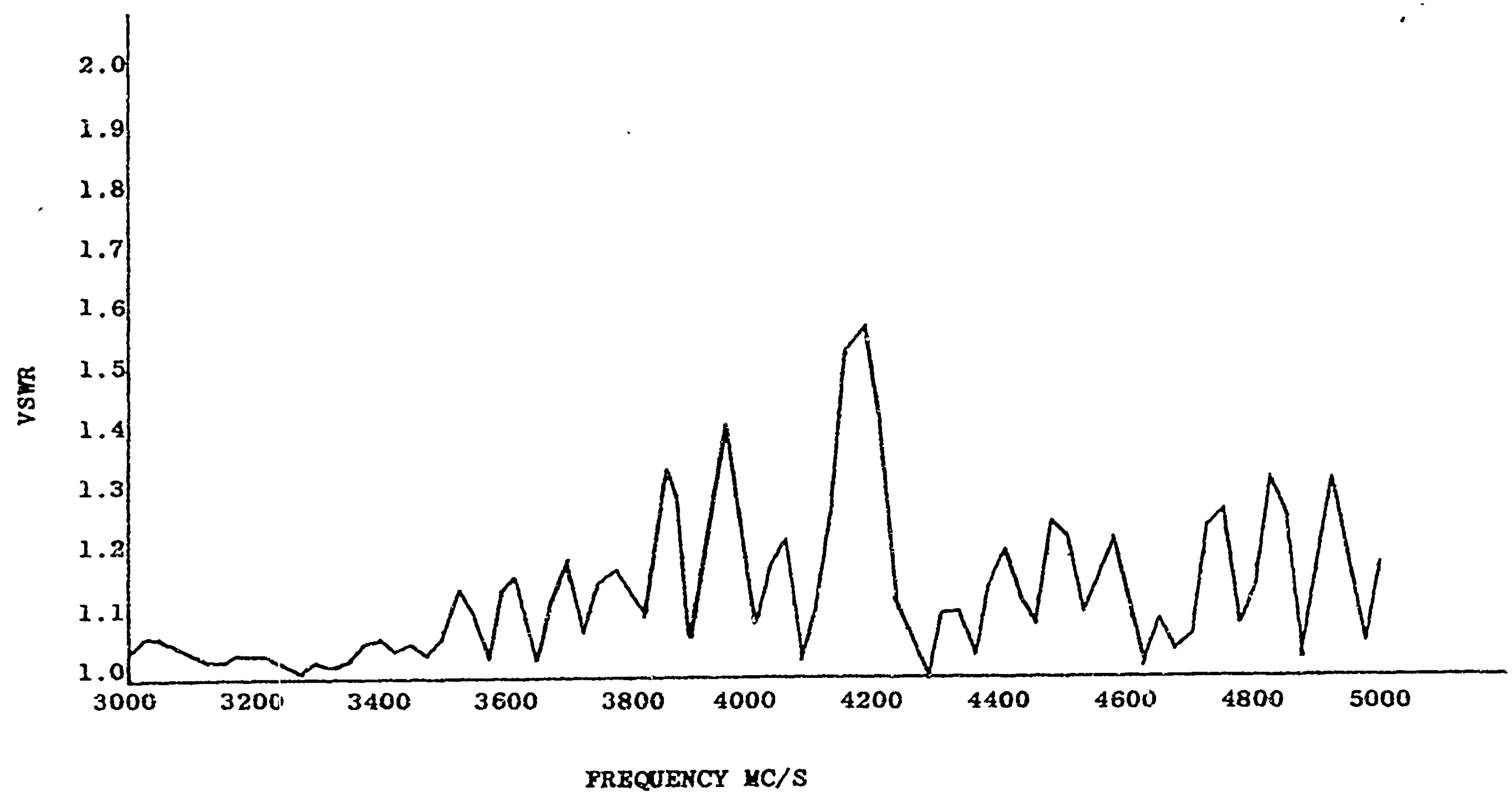


Figure 65.

CABLE "B"

VSWR of a 5 Foot Length of 7/8" H.T. HELIAX with Gas Barrier - Bent on a 20" diameter (See Test Procedure Par. 4.5.2)

VSWR after 10 Cycles of Thermal Shock
(Cable No. 1)

7/8" H.T. HELIAX
600 - 3000 MC

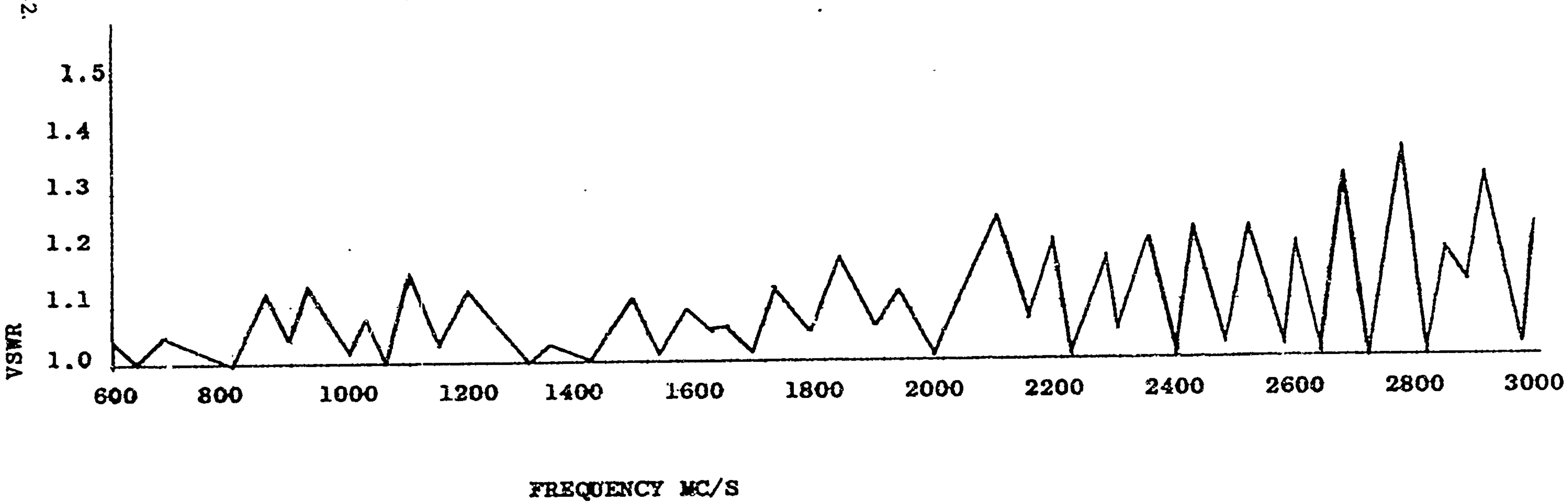


Figure 66.

Figure 67.

CABLE "B"

S.C. or F.P. No

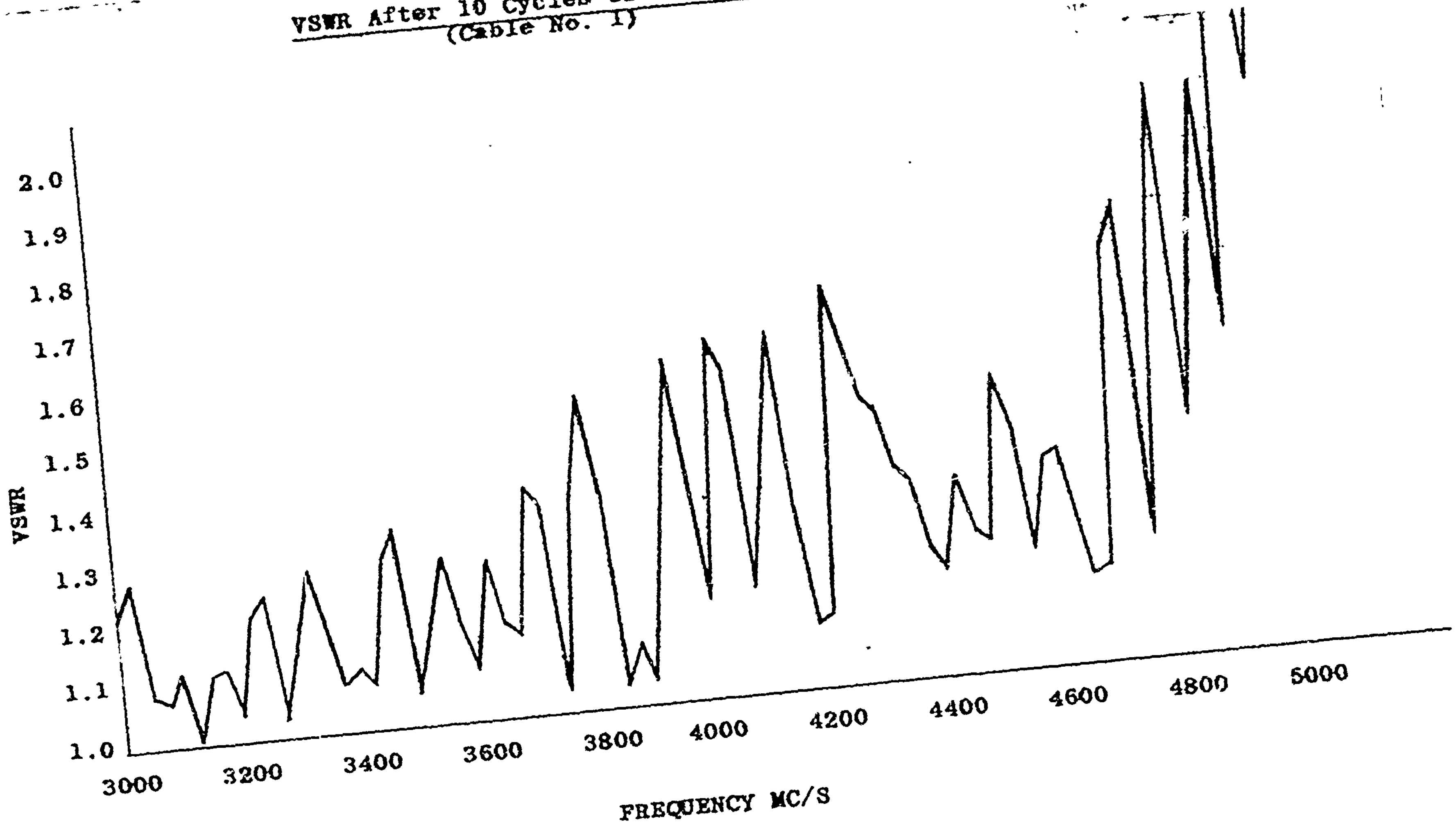
Type No

7/8" H.T. HELIAX

3000 - 5000 MC

VSWR of a 5 Foot length of 7/8" H.T. HELIAX with Gas Barrier - Bent on a 20" diameter (See Test Procedure Par. 4.5.2)

VSWR After 10 Cycles of Thermal Shock
(Cable No. 1)



CABLE "B"

VSWR of a 5 Foot Length of 7/8" H.T. HELIAX without Gas Barrier - Bent on a 20" diameter (See Test Procedure Par. 4.5.2)

VSWR after 10 Cycles of Thermal Shock
(Cable No. 1)

Type No

7/8" H.T. HELIAX
600 - 3000 MC

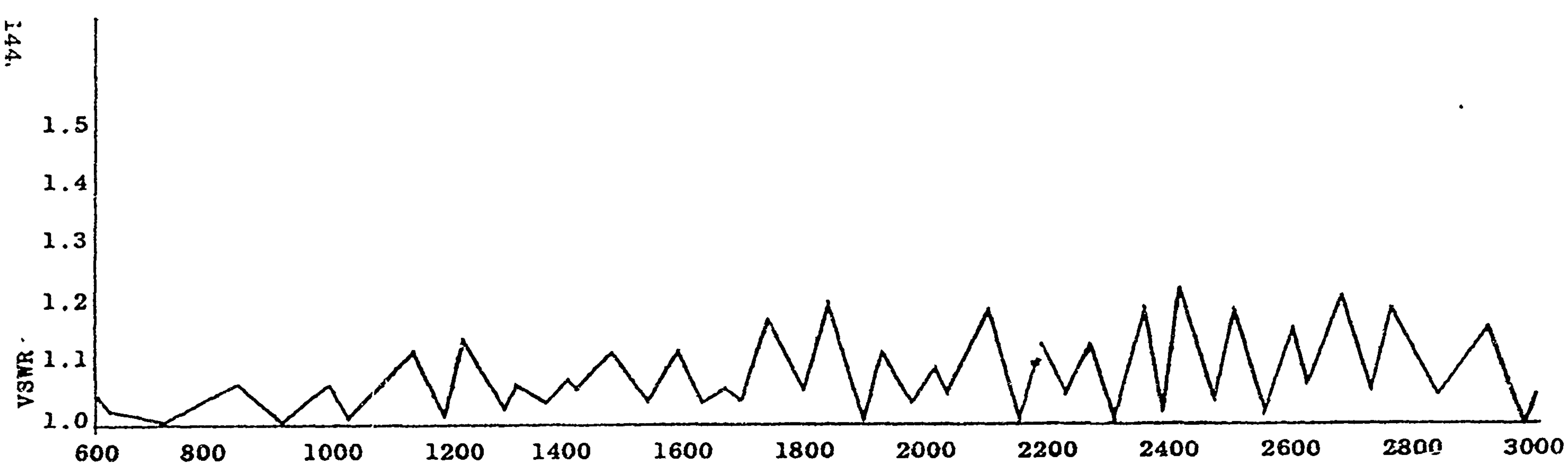


Figure 68.

CABLE "B"

VSWR of a 5 Foot length of 7/8" H.T. HELIAX without Gas Barriers - Bent on a 20" diameter
(See Test Procedure Par. 4.5.2)

VSWR after 10 Cycles of Thermal shock
(Cable No. 1)

7/8" H.T. HELIAX
3000 - 5000 MC

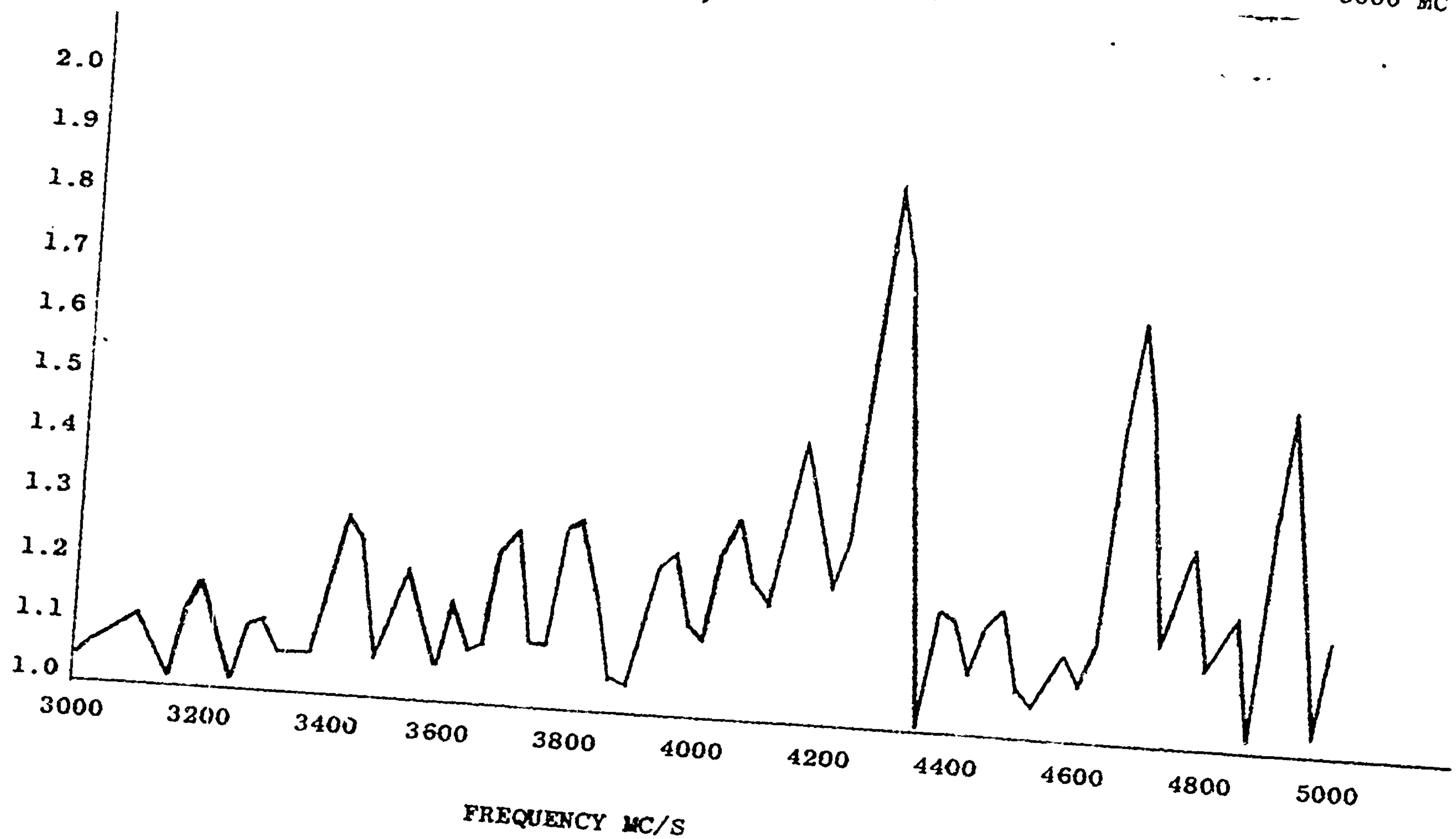


Figure 69.

CABLE "B"

VSWR of a 5 Foot Length of 7/8" H.T. HELIAX with Gas Barriers - Bent on a 20" diameter (See Test Procedure Par. 4.5.2)

7/8" H.T. HELIAX
600 - 5000 MC

VSWR before Thermal Shock
(Cable No. 2)

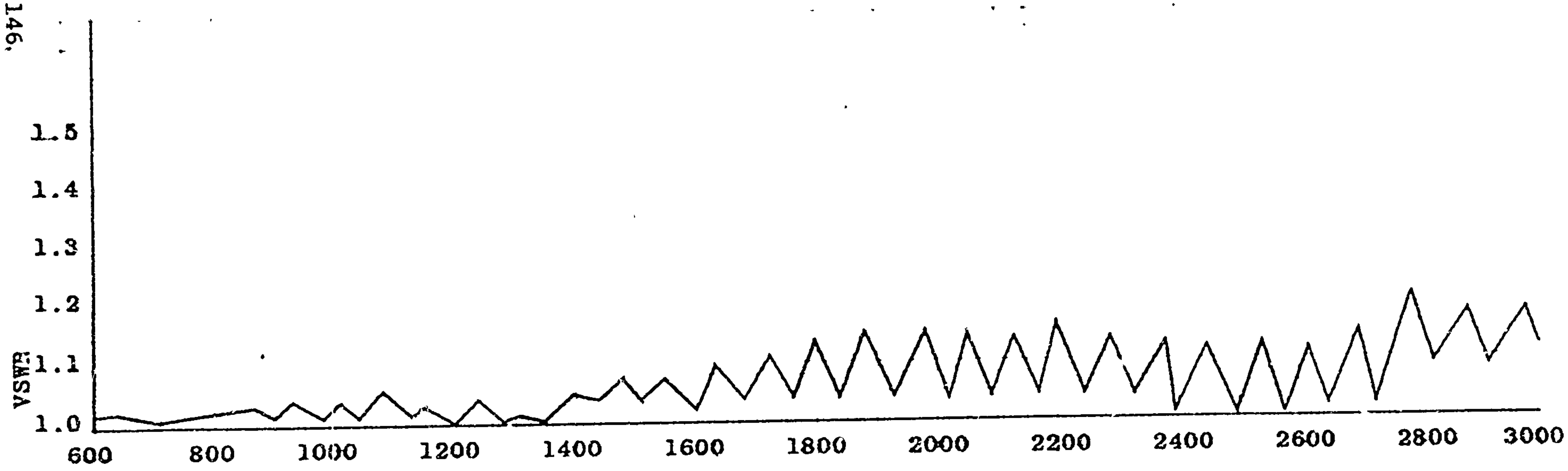


Figure 70.

CABLE "B"

VSWR of a 5 Foot Length of 7/8" M.T. HELIAX with Gas Barriers - Bent on a 20" diameter (See Test Procedure Par. 4.5.2)

7/8" M.T. HELIAX
3000 - 5000 MC

VSWR Before Thermal Shock
(Cable No. 2)

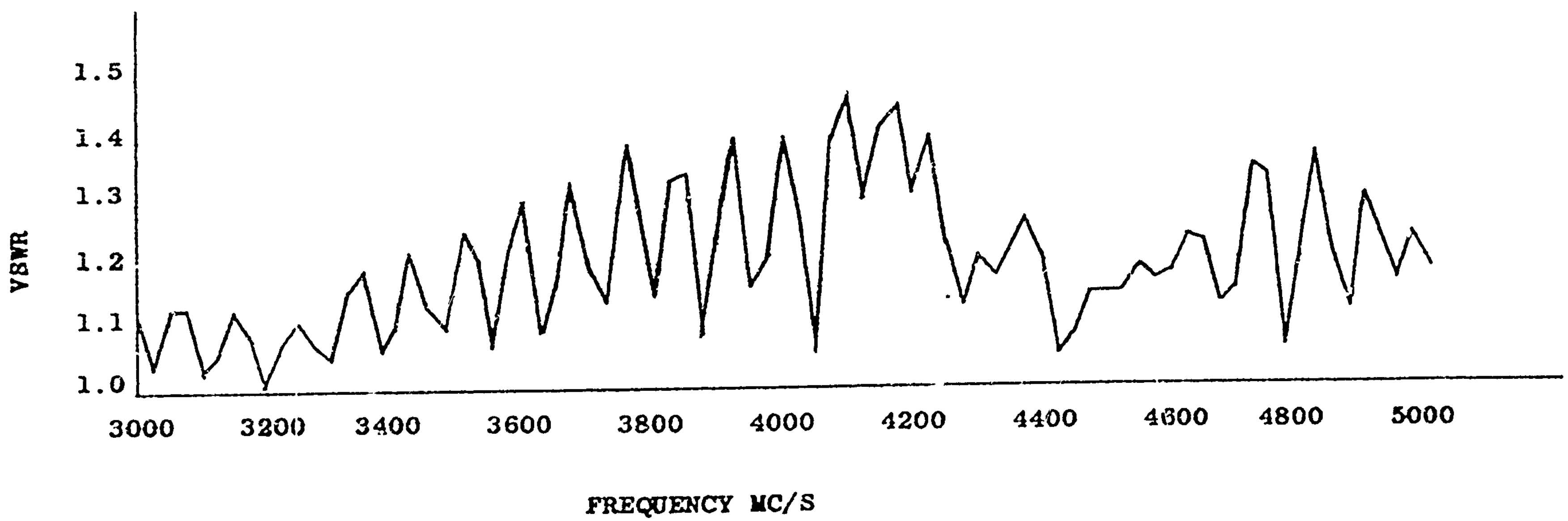


Figure 71.

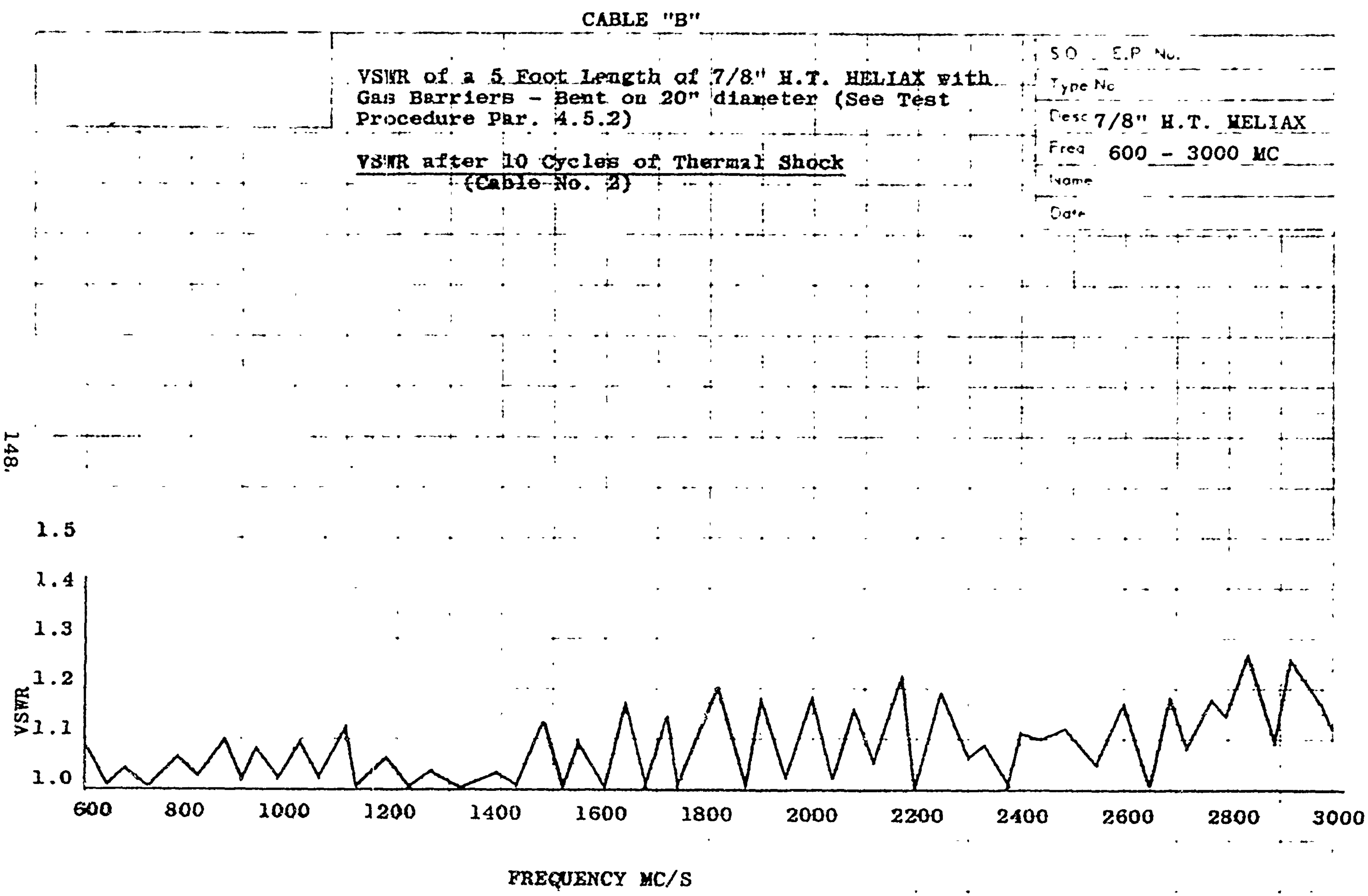
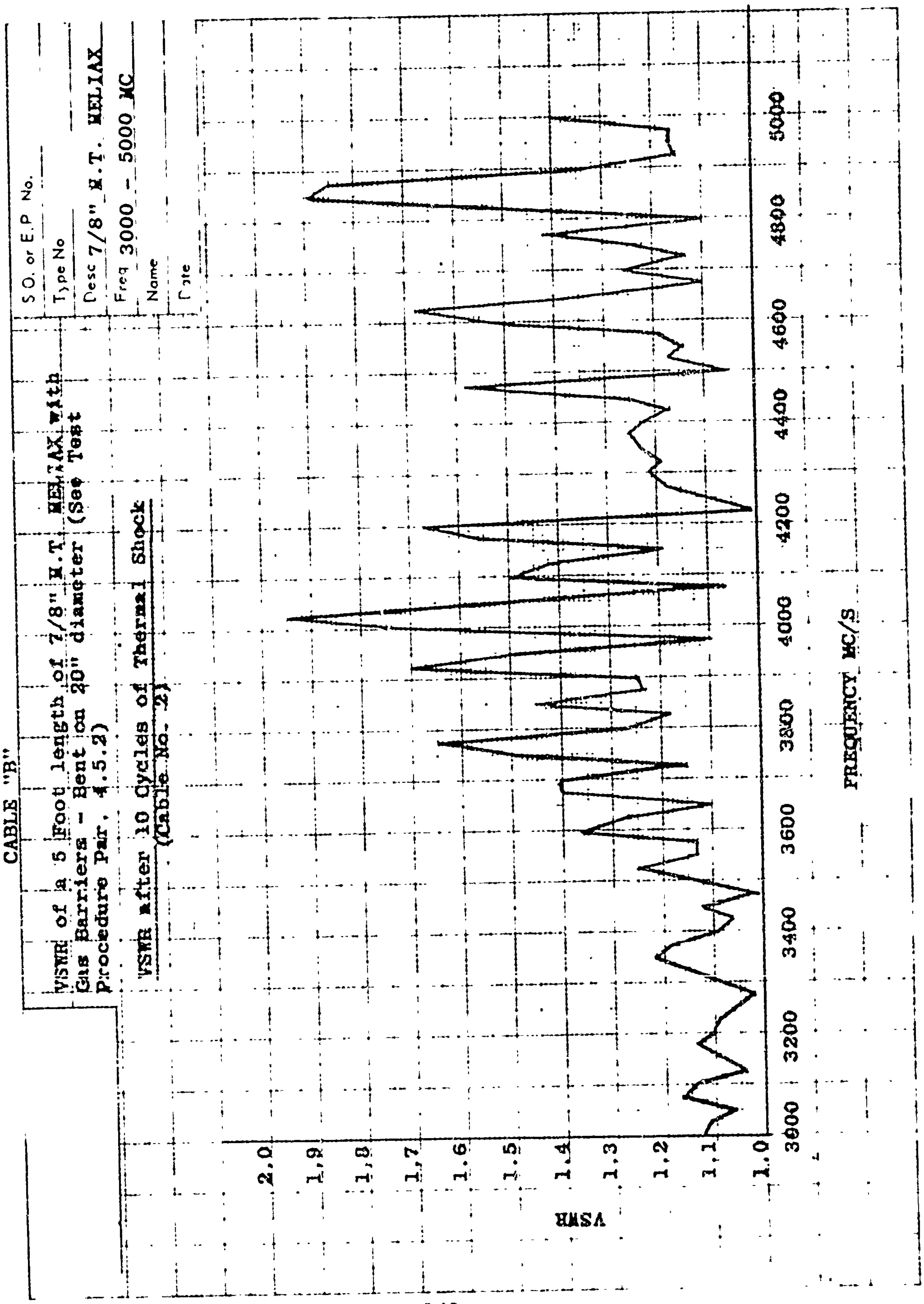

CABLE "B"
VSWR of a 5 Foot Length of 7/8" H.T. HELIAX with Gas Barriers - Bent on 20" diameter (See Test Procedure Par. 4.5.2)
VSWR after 10 Cycles of Thermal Shock (Cable No. 2)
S.O. E.P. No.
Type No.
Desc 7/8" H.T. HELIAX
Freq 600 - 3000 MC
Name
Date
VSWR
1.0
1.1
1.2
1.3
1.4
1.5
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
FREQUENCY MC/S

Figure 72.


CABLE "B"
VSWR of a 5 Foot length of 7/8" H.T. HELIAX with Gas Barriers - Bent on 20" diameter (See Test Procedure Par. 4.5.2)
VSWR after 10 Cycles of Thermal Shock (Cable No. 2)
S.O. or E.P. No.
Type No
Desc 7/8" H.T. HELIAX
Freq 3000 - 5000 MC
Name
Date
VSWR
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
FREQUENCY MC/S

CABLE "B"

VSWR of a 5 Foot Length of 7/8" H.T. HELIAX with Gas Barriers - Bent on 20" diameter (See Test Procedure Par. 4.5.2)

VSWR after 25 Cycles of Thermal Shock (Cable No. 2)

S.O. or E P No

Type No

Desc 7/8" H.T. HELIAX

Freq 600 - 5000 MC

Name

Date

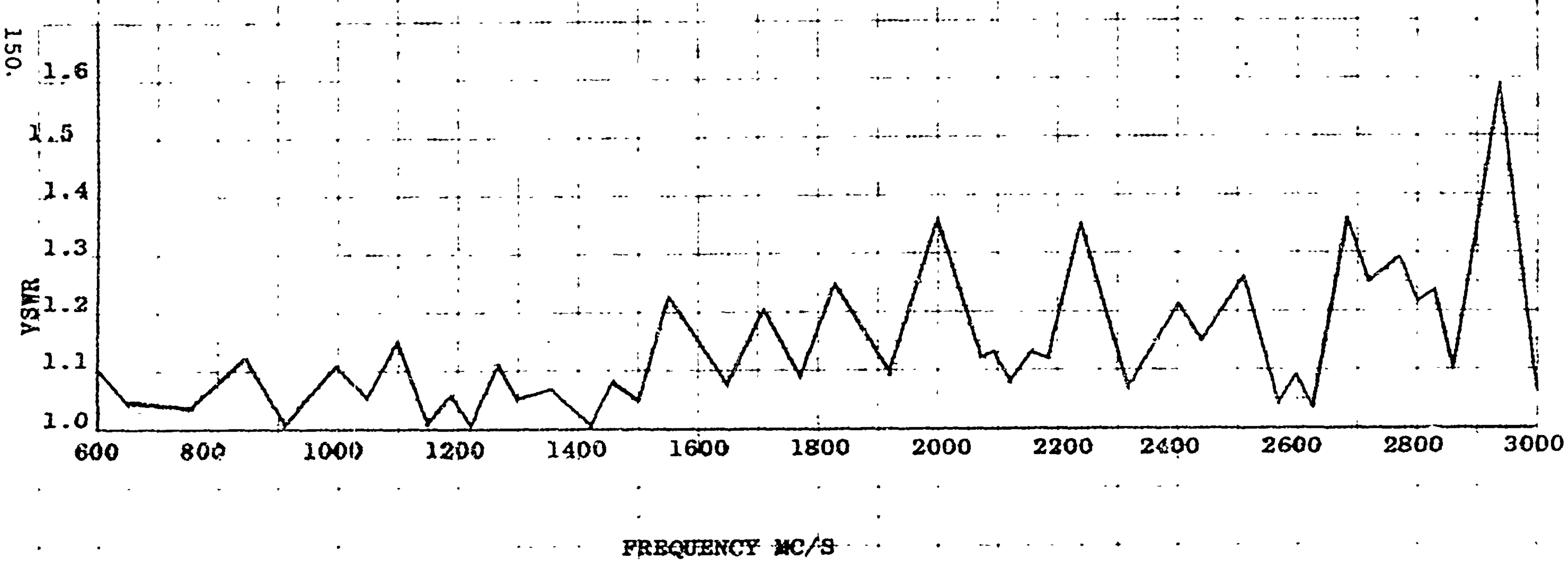


Figure 74.

Figure 75.

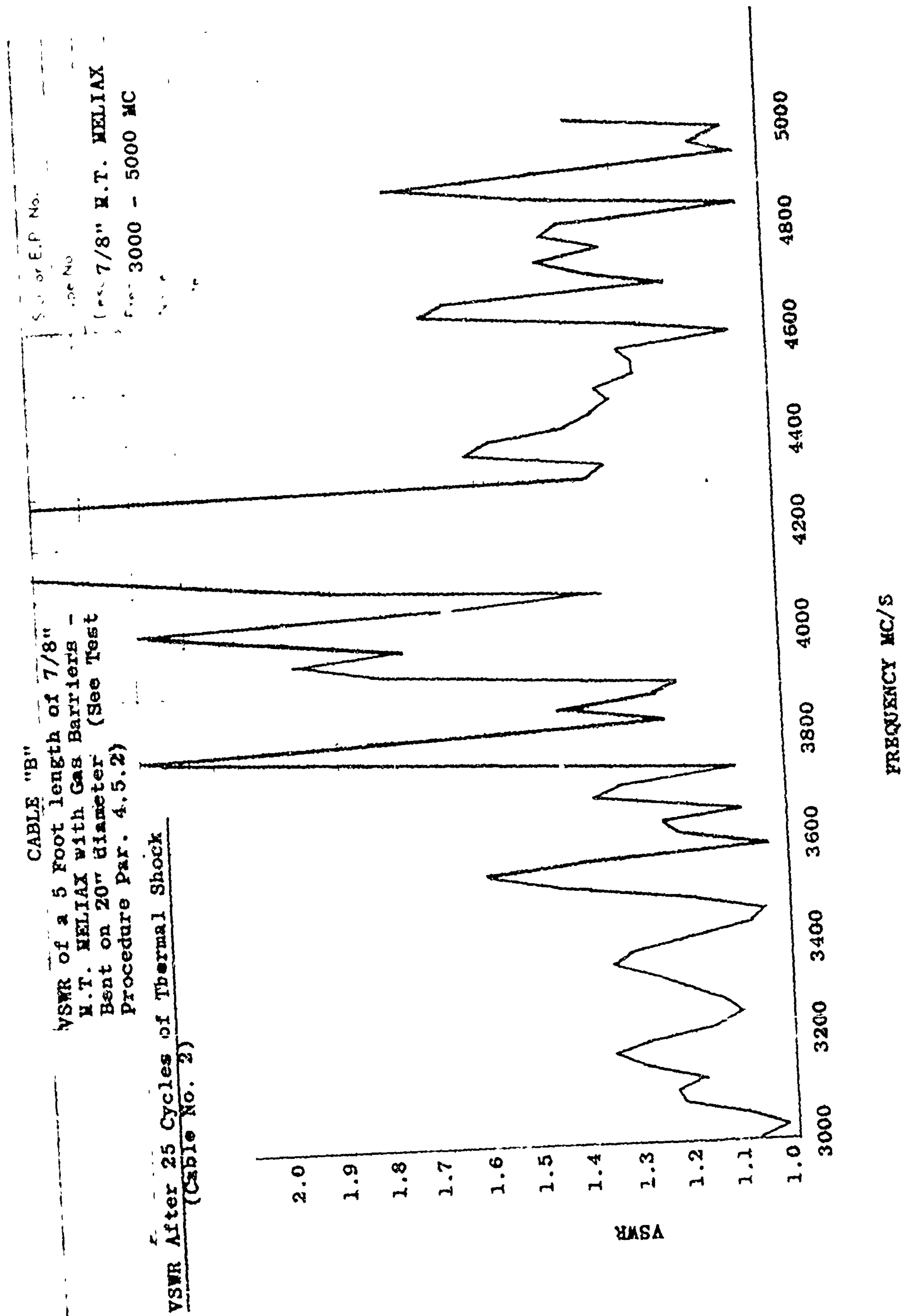
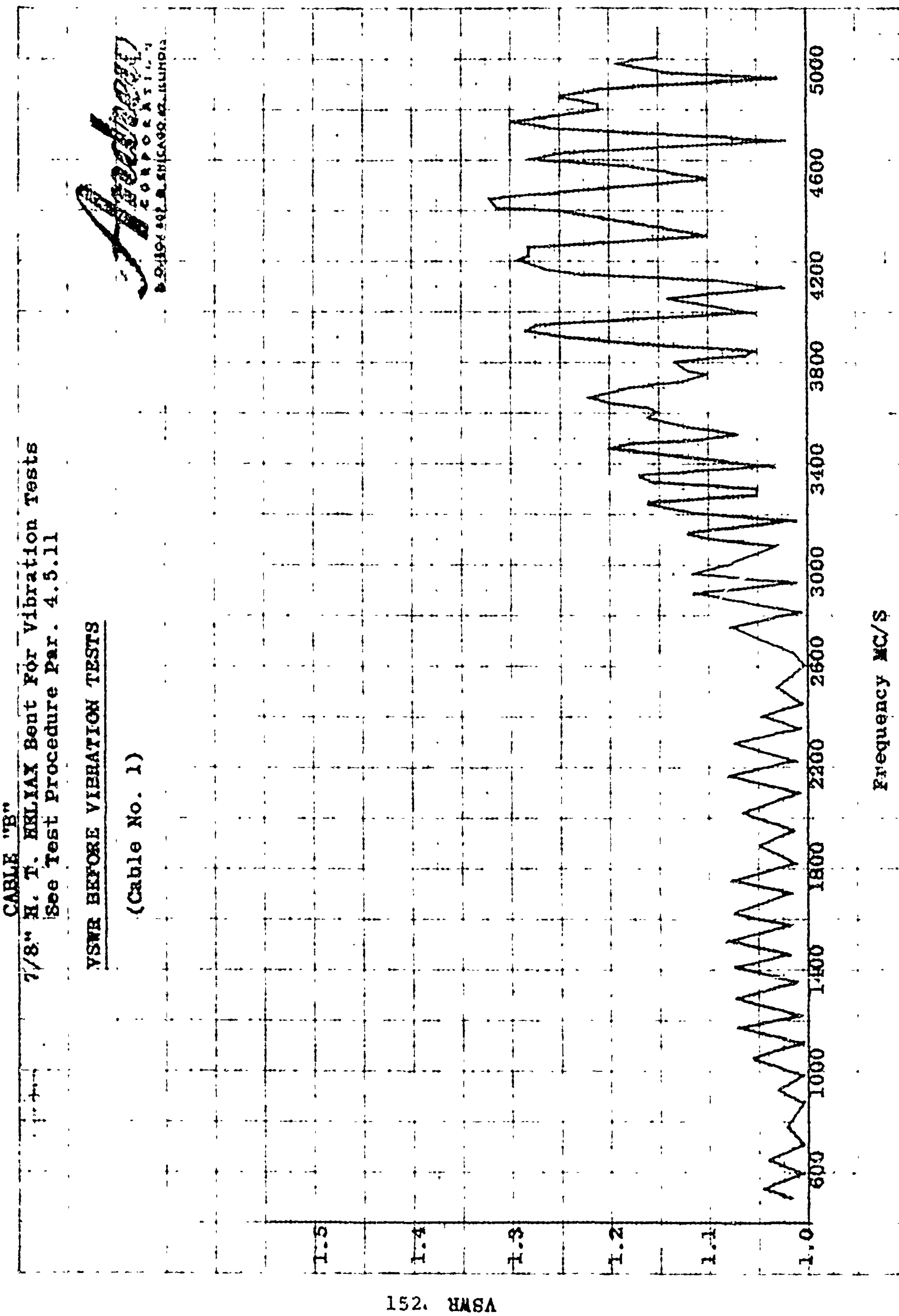

CABLE "B"
VSWR of a 5 Foot length of 7/8"
H.T. HELIAX with Gas Barriers -
Bent on 20" diameter (See Test
Procedure Par. 4.5.2)
VSWR After 25 Cycles of Thermal Shock
(Cable No. 2)
7/8" H.T. HELIAX
3000 - 5000 MC
VSWR
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
FREQUENCY MC/S

Figure 76.


CABLE "B"
7/8" H. T. HELIAX Bent For Vibration Tests
See Test Procedure Par. 4.5.11
VSWR BEFORE VIBRATION TESTS
(Cable No. 1)
1.0
1.1
1.2
1.3
1.4
1.5
600
1000
1400
1800
2200
2600
3000
3400
3800
4200
4600
5000
Frequency MC/S
VSWR

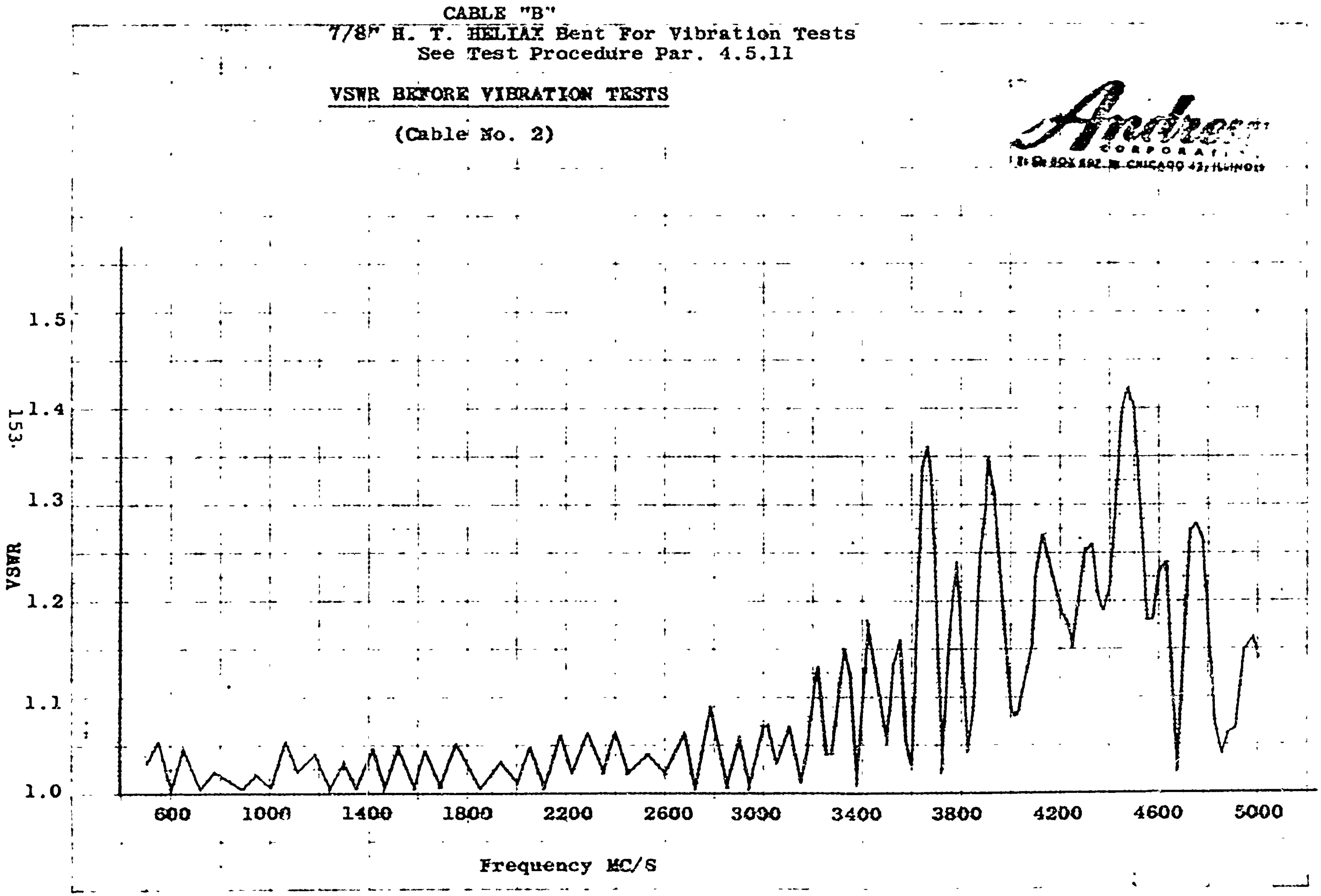

CABLE "B"
7/8" H. T. HELIAX Bent For Vibration Tests
See Test Procedure Par. 4.5.11
VSWR BEFORE VIBRATION TESTS
(Cable No. 2)
Andrew Corporation
VSWR
1.5
1.4
1.3
1.2
1.1
1.0
600
1000
1400
1800
2200
2600
3000
3400
3800
4200
4600
5000
Frequency MC/S

Figure 77.

Figure 78.

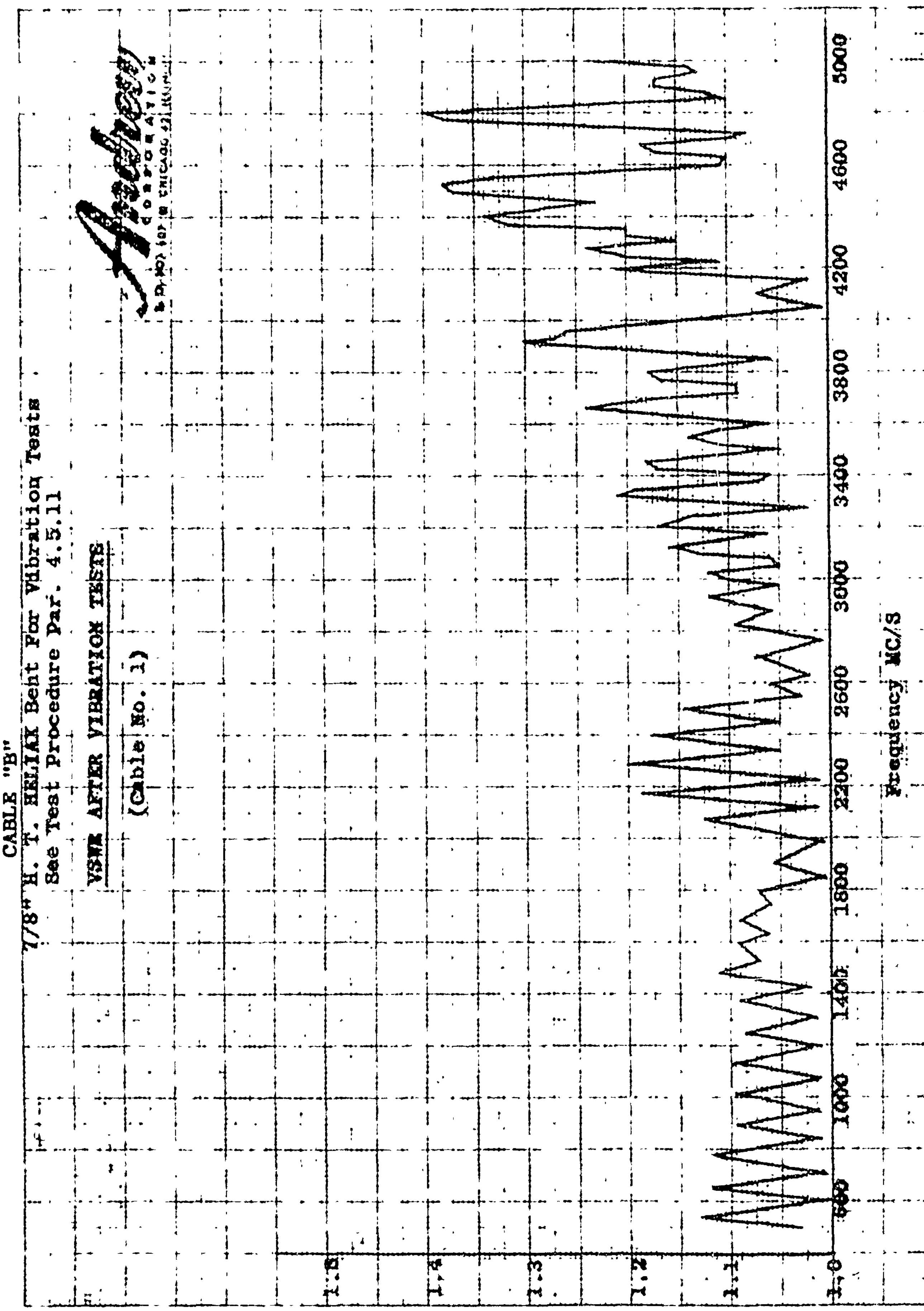

CABLE "B"
7/8" H. T. HELIAX Bent For Vibration Tests
See Test Procedure Par. 4.5.11
VSWR AFTER VIBRATION TESTS
(Cable No. 1)
Frequency MC/S
600
1000
1400
1800
2200
2600
3000
3400
3800
4200
4600
5000
1.0
1.1
1.2
1.3
1.4
1.5
VSWR

Figure 79.

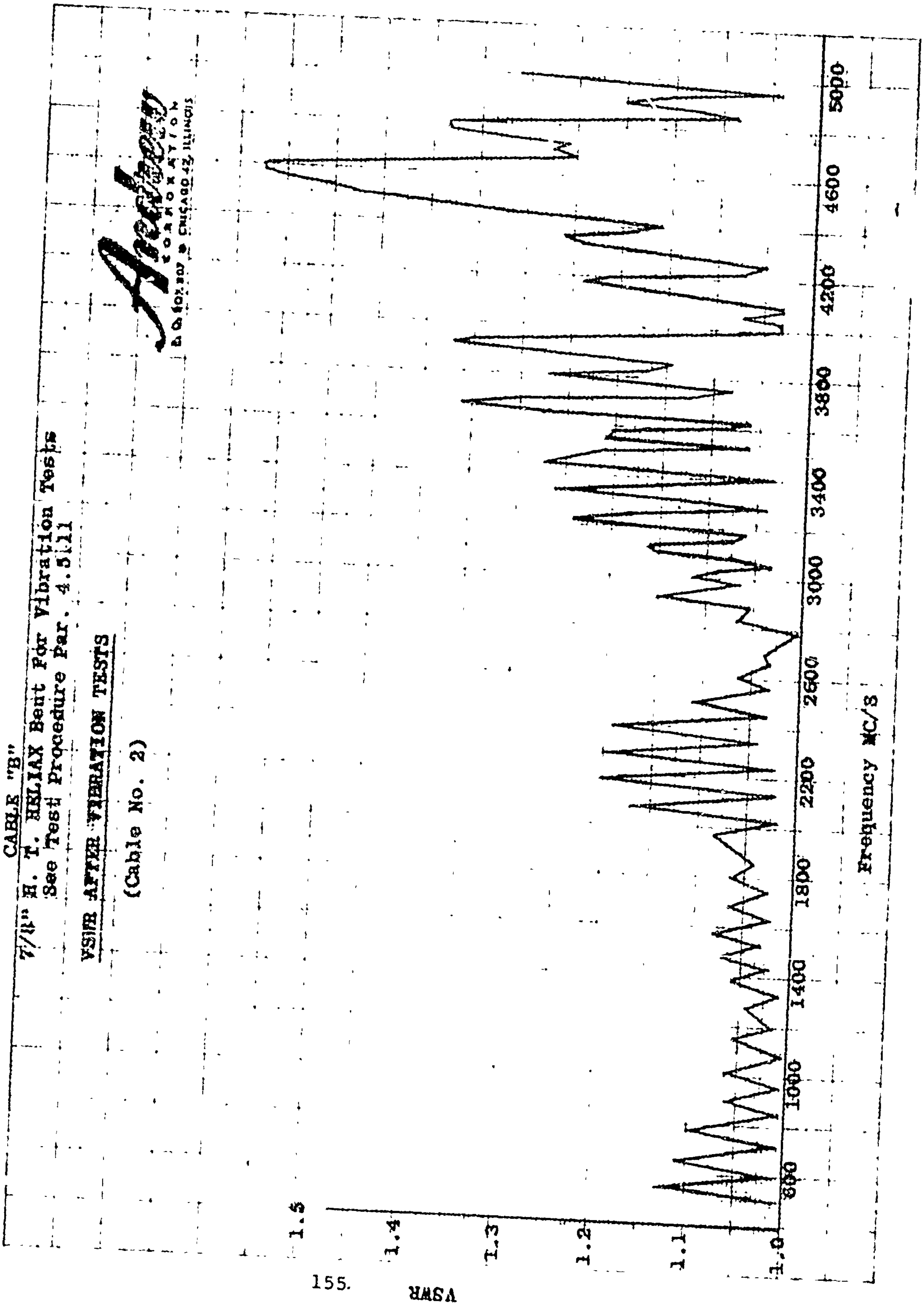
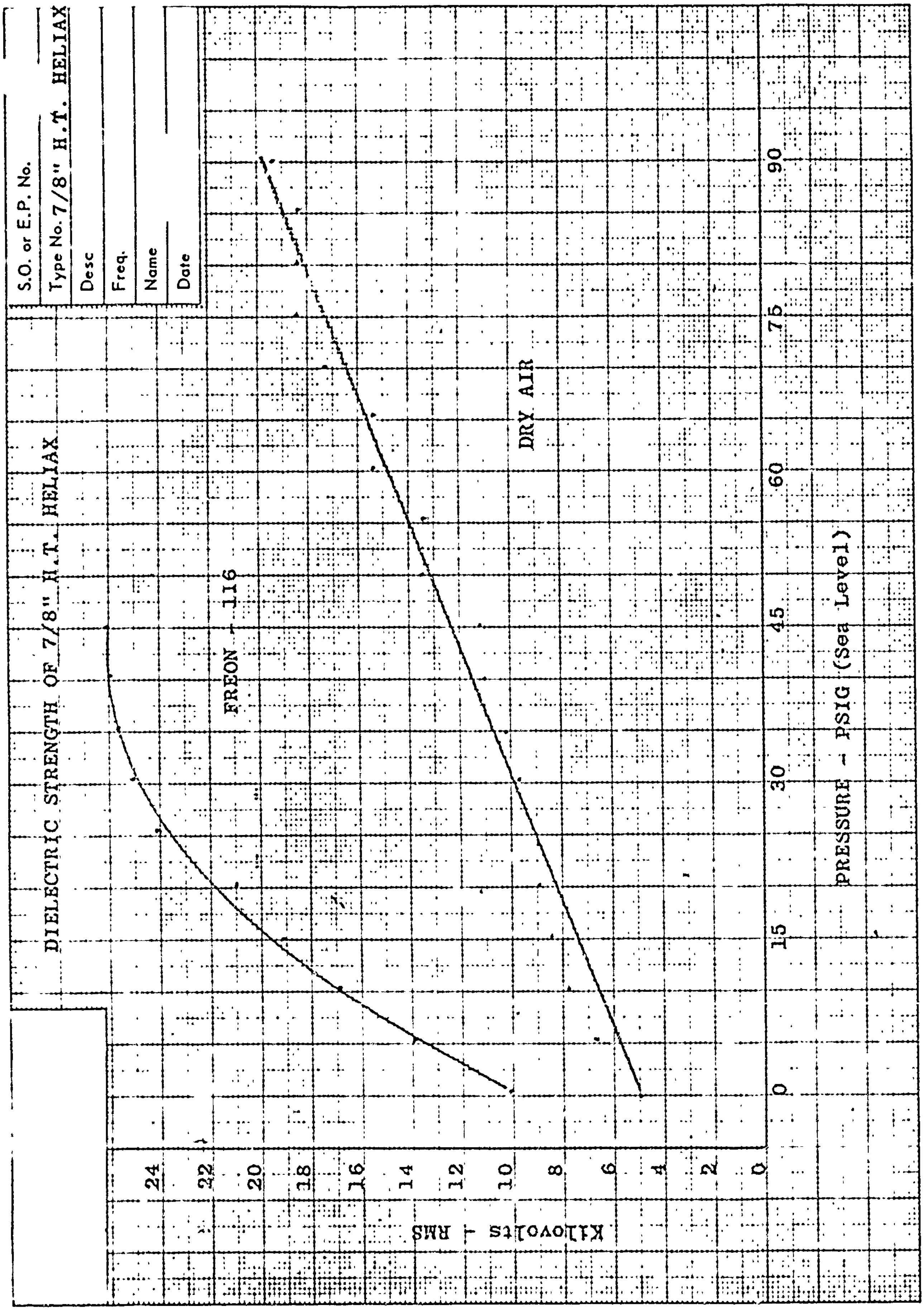
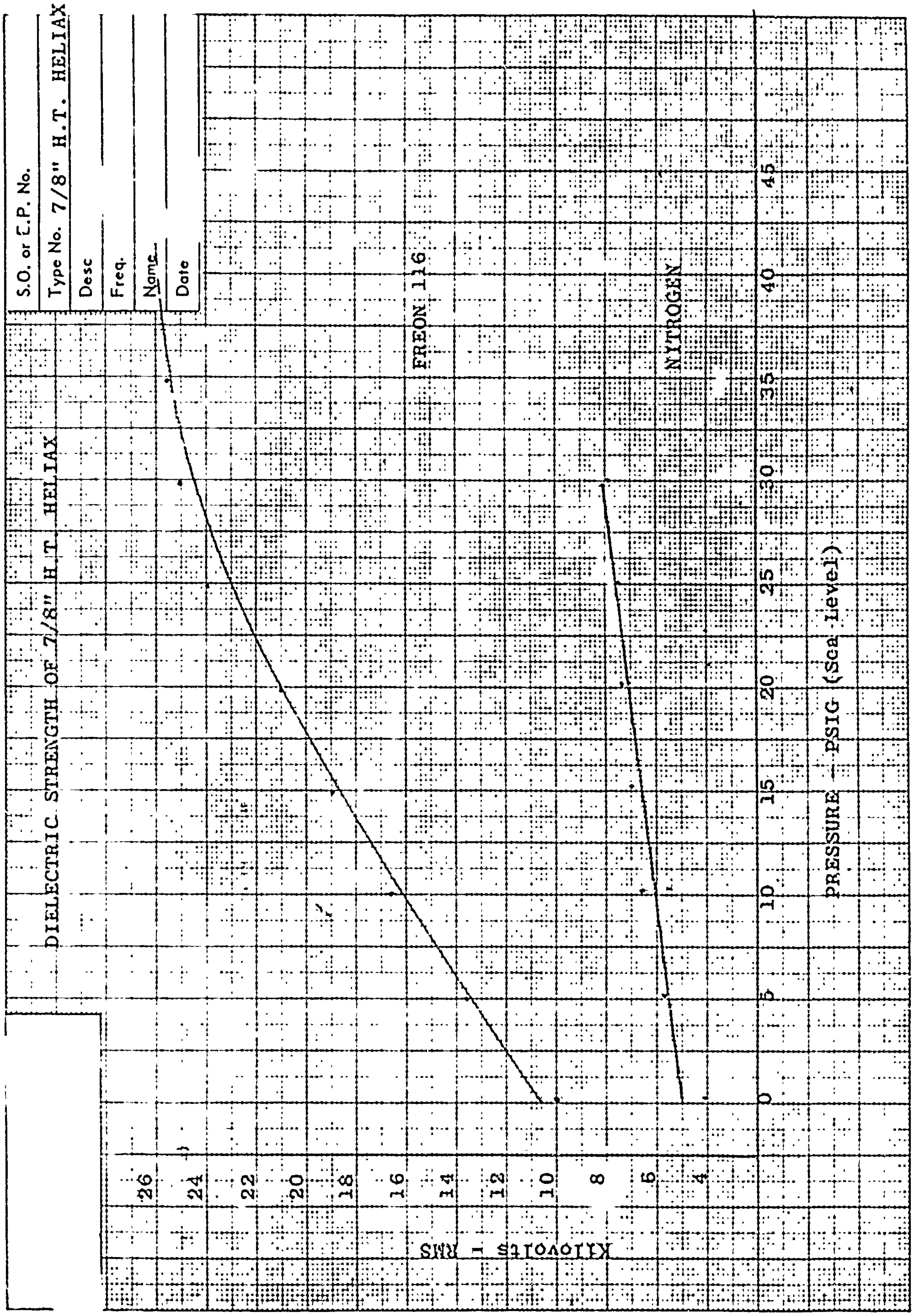

CABLE "B"
7/8" H. T. HELIAX Bent For Vibration Tests
See Test Procedure Par. 4.5.11
VSWR AFTER VIBRATION TESTS
(Cable No. 2)
Andrew CORPORATION
P. O. BOX 807 CHICAGO 42, ILLINOIS
VSWR
1.0
1.1
1.2
1.3
1.4
1.5
Frequency MC/S
600
1000
1400
1800
2200
2600
3000
3400
3800
4200
4600
5000

Figure 80.



S.O. or E.P. No.
Type No. 7/8" H.T. HELIAX
Desc
Freq.
Name
Date
DIELECTRIC STRENGTH OF 7/8" H.T. HELIAX
FREON - 116
DRY AIR
Kilovolts - RMS
0
2
4
6
8
10
12
14
16
18
20
22
24
PRESSURE - PSIG (Sea Level)
0
15
30
45
60
75
90

Figure 81.


S.O. or C.P. No.
Type No. 7/8" H.T. HELIAX
Desc
Freq.
Name
Date
DIELECTRIC STRENGTH OF 7/8" H.T. HELIAX
FREON 116
NITROGEN
0 5 10 15 20 25 30 35 40 45
PRESSURE – PSIG (Sea Level)
26 24 22 20 18 16 14 12 10 8 6 4
KILOVOLTS – RMS

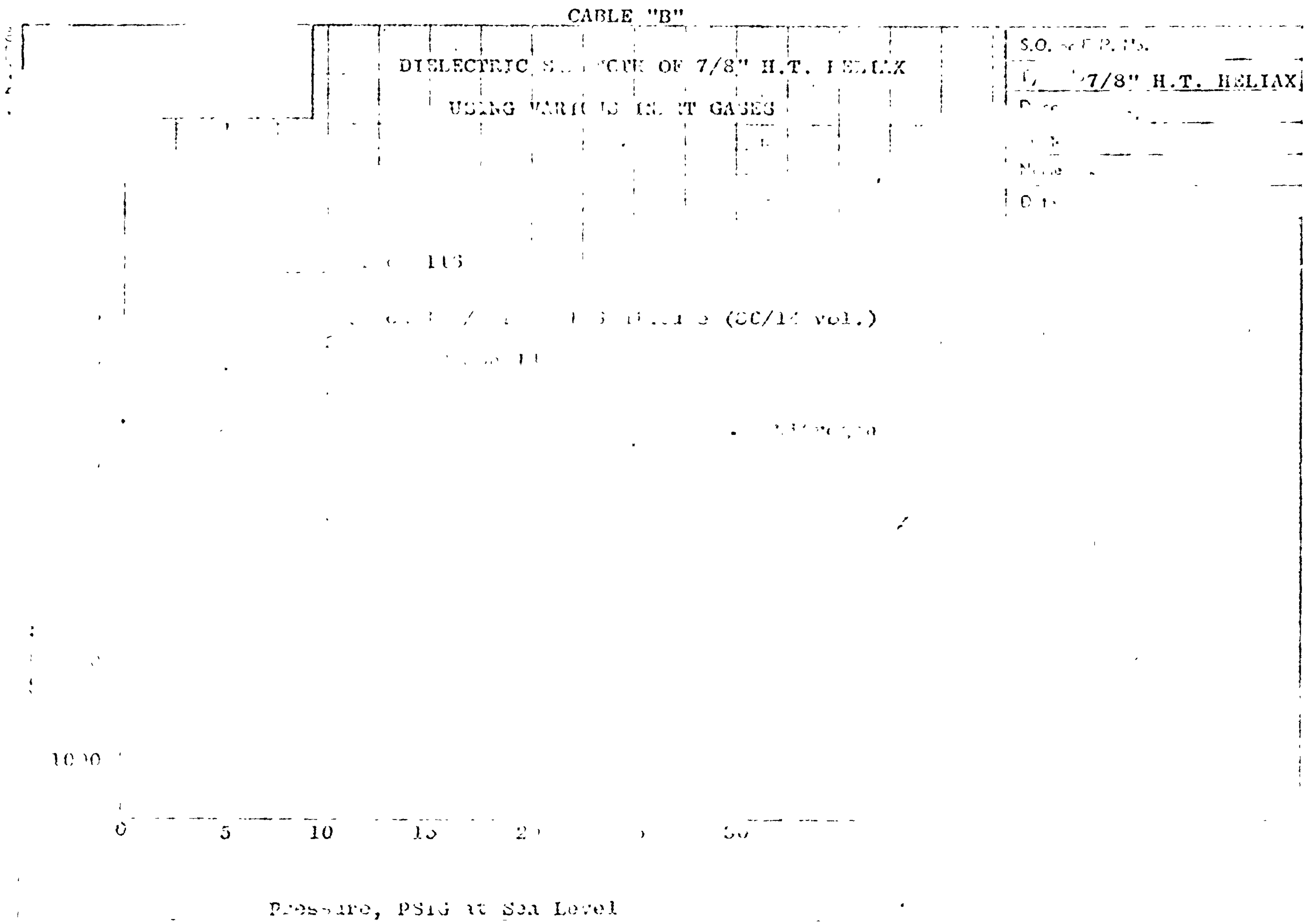
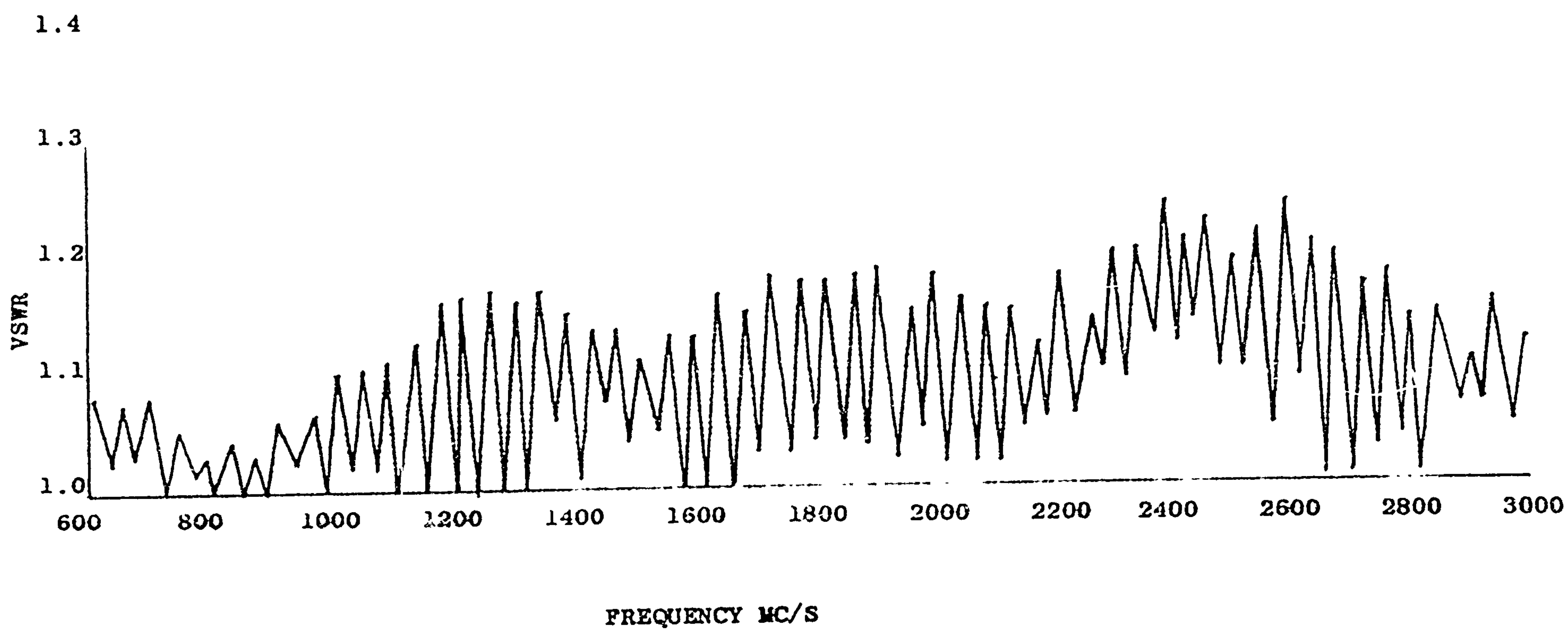

CABLE "B"
7/8" H.T. HELIAX
USING
GASES
(CC/1 vol.)
1000
0
5
10
15
2
50
Pressure, PSIG at Sea Level

Figure 62.

CABLE "B"

VSWR of Prototype Cable No. 1 shipped to ASD
10 Foot Lengths of 7/8" H.T. HELIAX with connectors

7/8" H.T. HELIAX
600 to 3000 MC



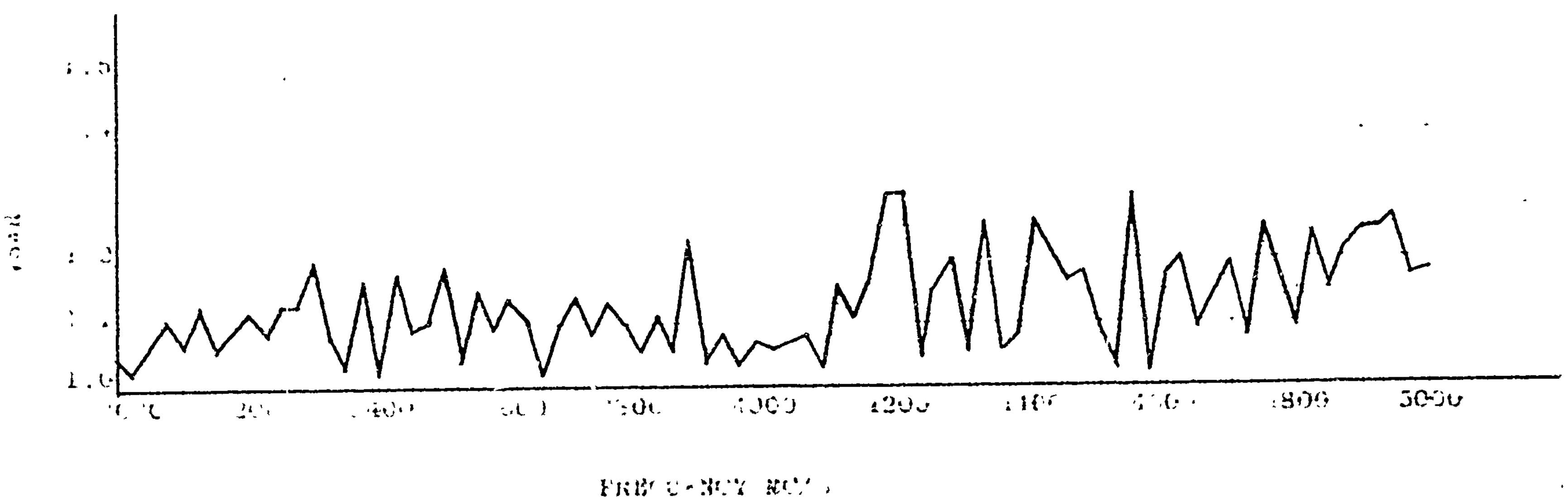
Figure

Figure 84.

CABLE "3"

VSWR of Prototype Cable No. 1 shipped to ASD
10 Foot Length of 7/8" R.T. HELIAX with connector

S.O. or E.P. No.	
Type No	
Desc	
Freq	
Name	
Date	



CABLE "B"

VSWR of Prototype Cable No. 1 shipped to ASD
10 Foot Length of 7/8" M.T. HELIAX with connectors
and Gas Barriers

S.O. or E.P. No.
Type No.
7/8" M.T. HELIAX
Fre 600 - 3000 MC
Name
Date

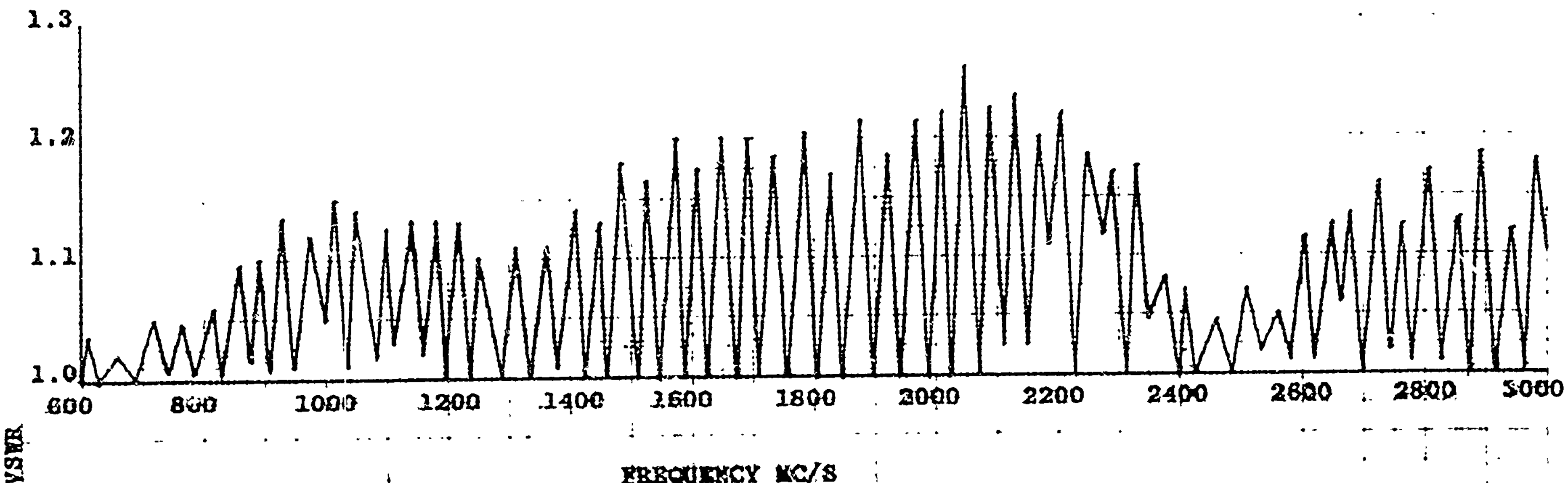
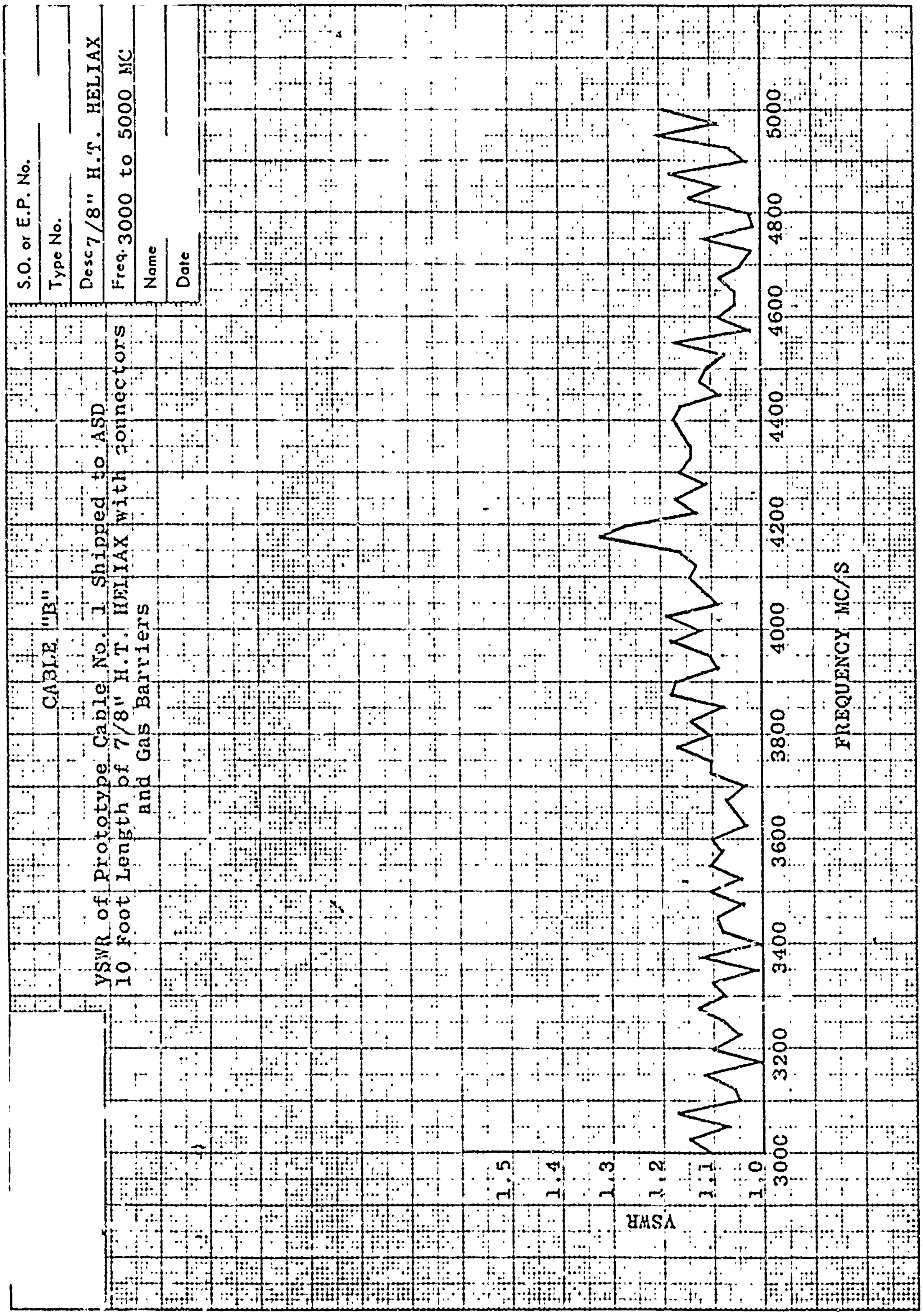


Figure 85.

Figure 86.


S.O. or E.P. No.
Type No.
Desc 7/8" H.T. HELIAX
Freq. 3000 to 5000 MC
Name
Date
CABLE "B"
VSWR of Prototype Cable No. 1 Shipped to ASD
10 Foot Length of 7/8" H.T. HELIAX with connectors
and Gas Barriers
VSWR
1.5
1.4
1.3
1.2
1.1
1.0
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
FREQUENCY MC/S

CABLE "B"

VSWR of Prototype Cable No. 2 shipped to ASD
10 Foot Length of 7/8" H.T. HELIAX with connectors

7 8" H.T. HELIAX
600 to 3000 MC

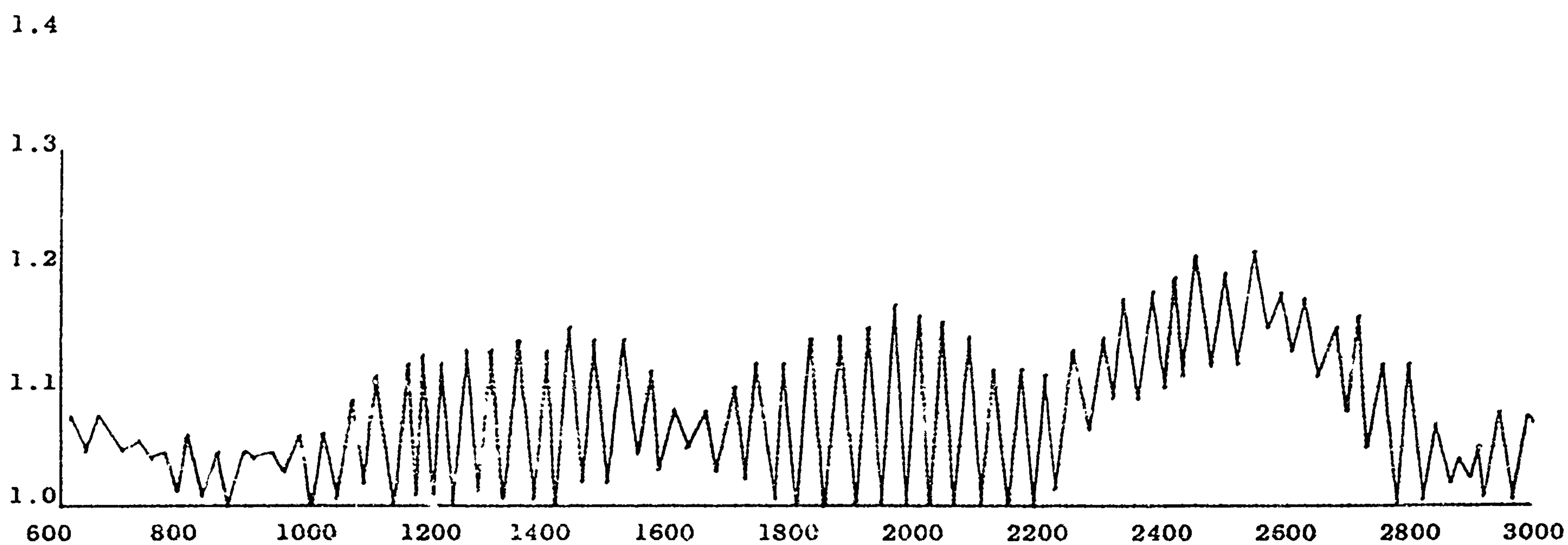
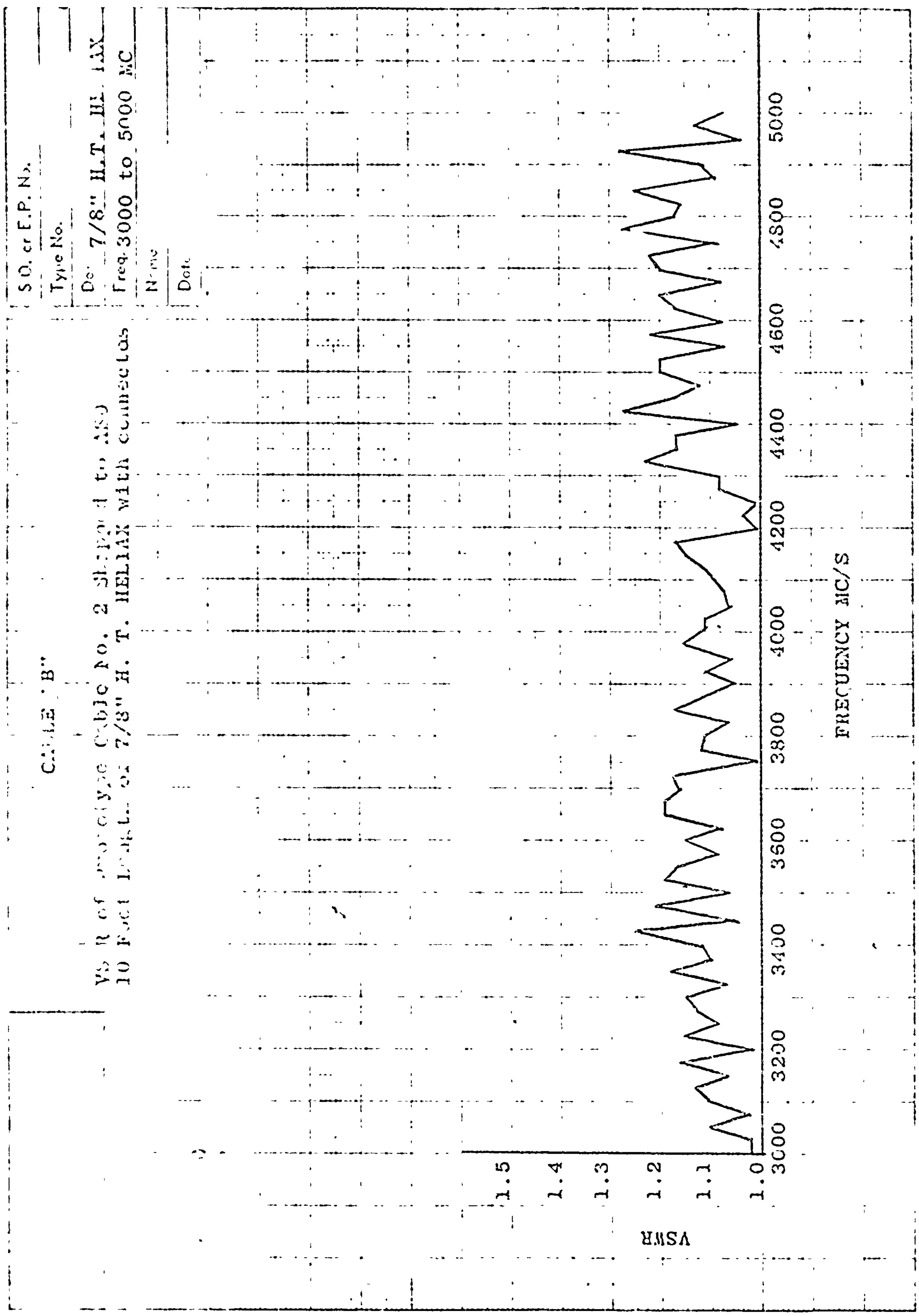


Figure 87.

Figure 88.


S.O. or E.P. No.
Type No.
Des. 7/8" H.T. HELIAX
Freq. 3000 to 5000 MC
Name
Date
CABLE 'B'
HELIAX with connectors
VSWR
1.5
1.4
1.3
1.2
1.1
1.0
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
FREQUENCY MC/S

CABLE "B"

VSWR of Prototype Cable No. 2 shipped to ASD.
10 Foot Length of 7/8" H.T. HELIAX with connectors and Gas Barriers.

Type No
Desc 7/8" H.T. HELIAX
Freq 600 - 3000 MC
Name
Date

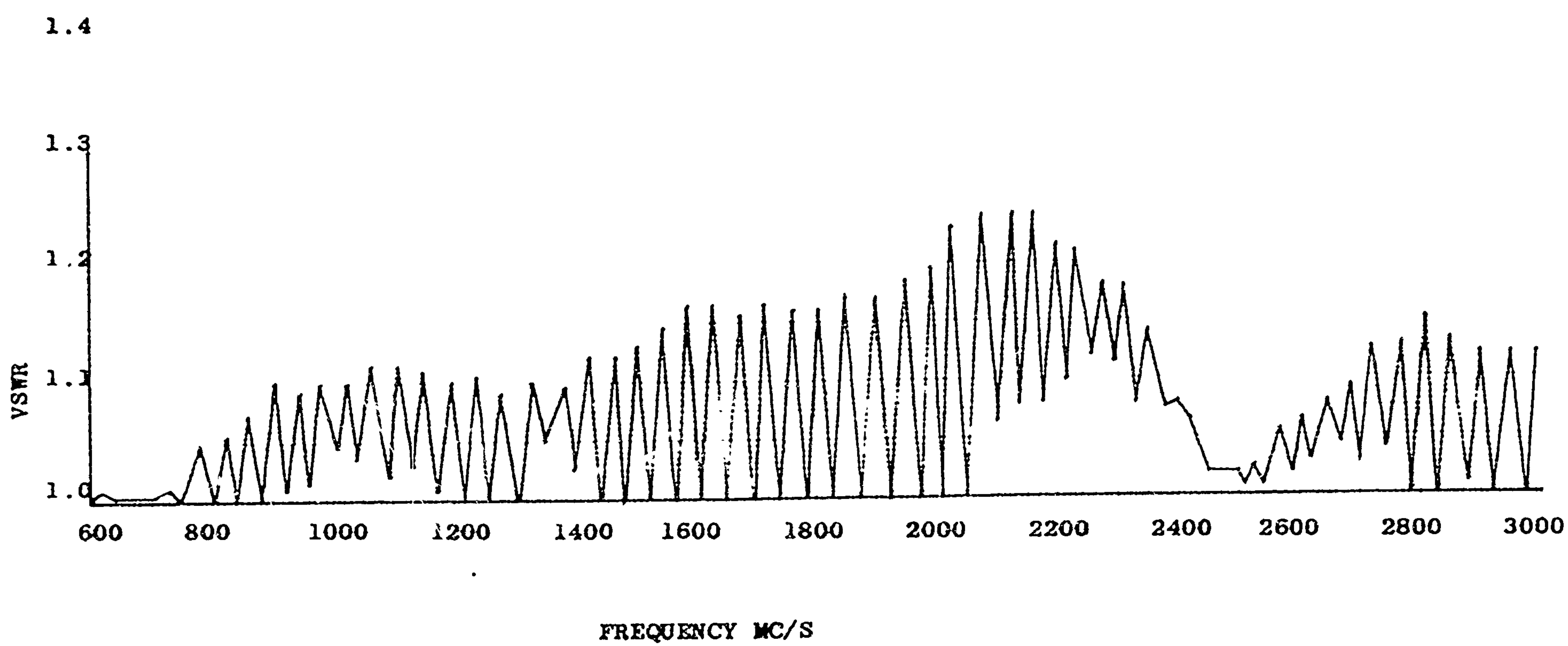
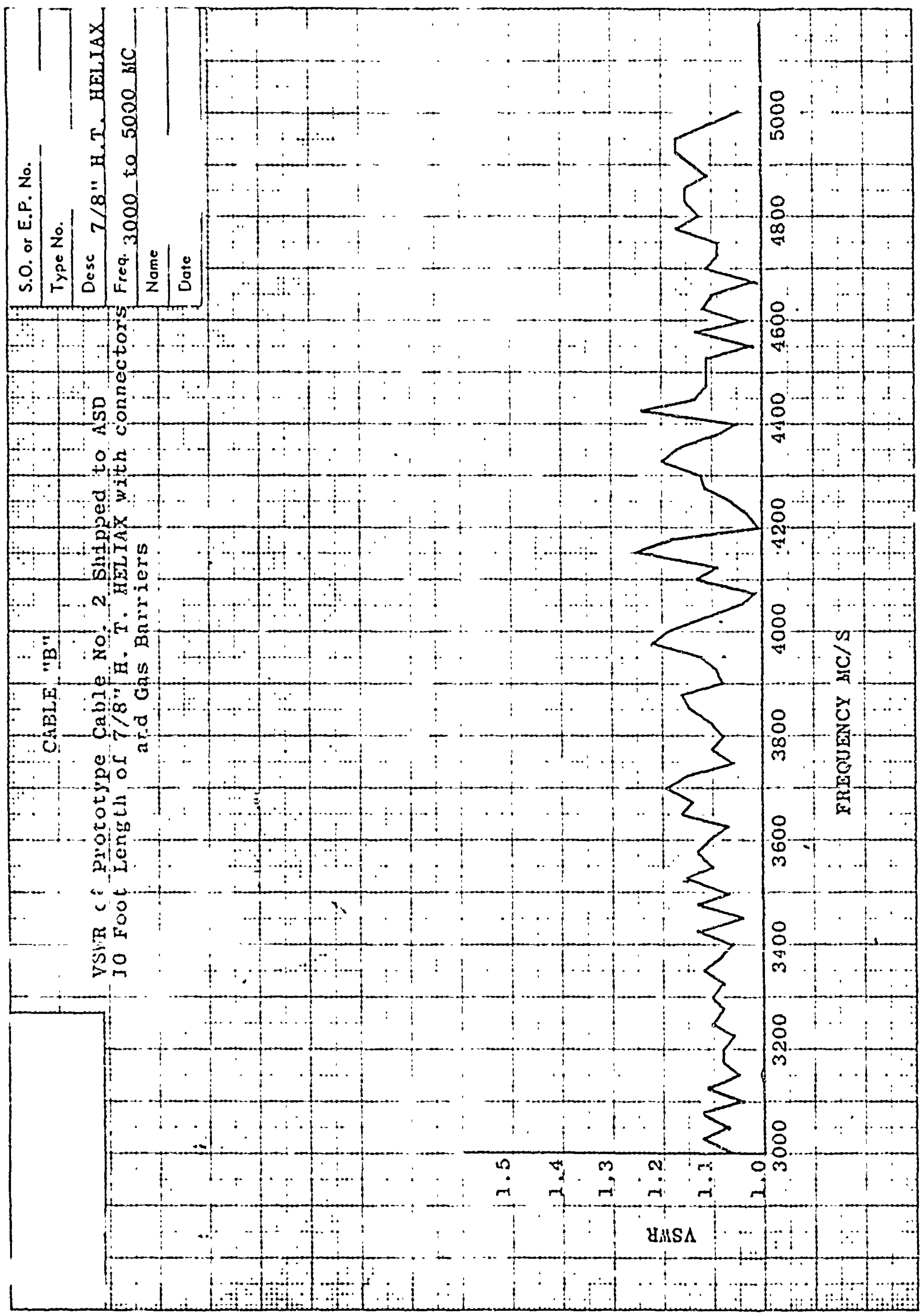


Figure 89.

Figure 90.

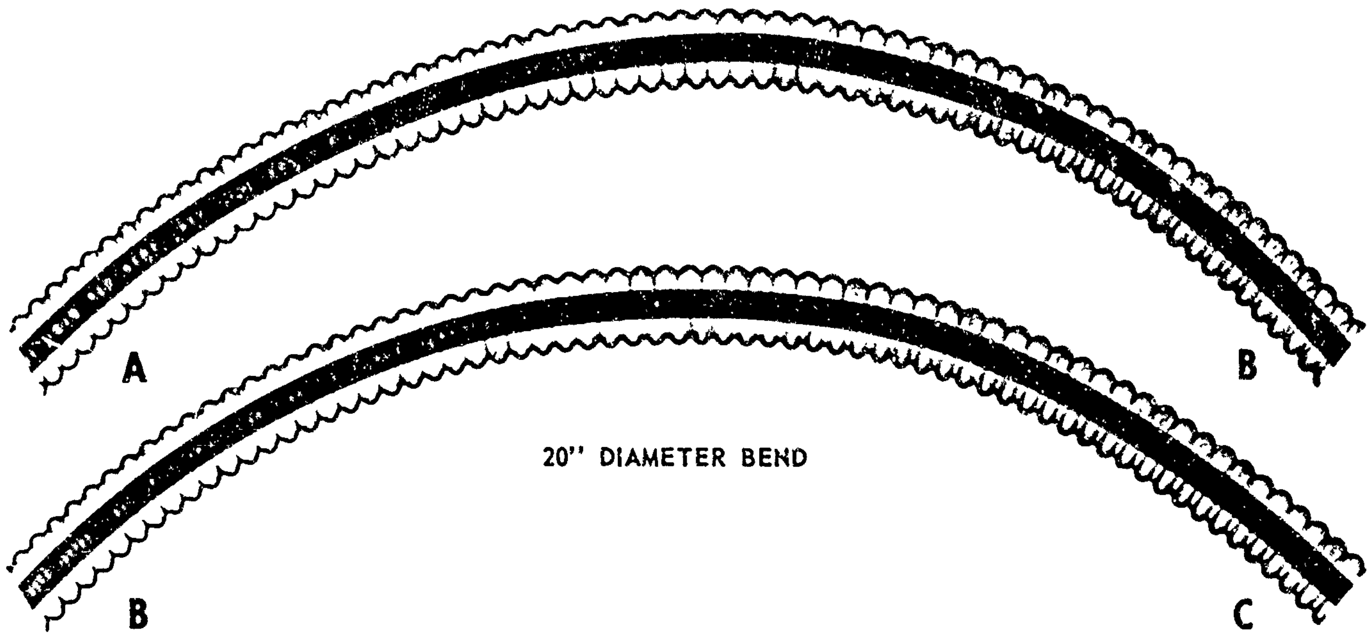


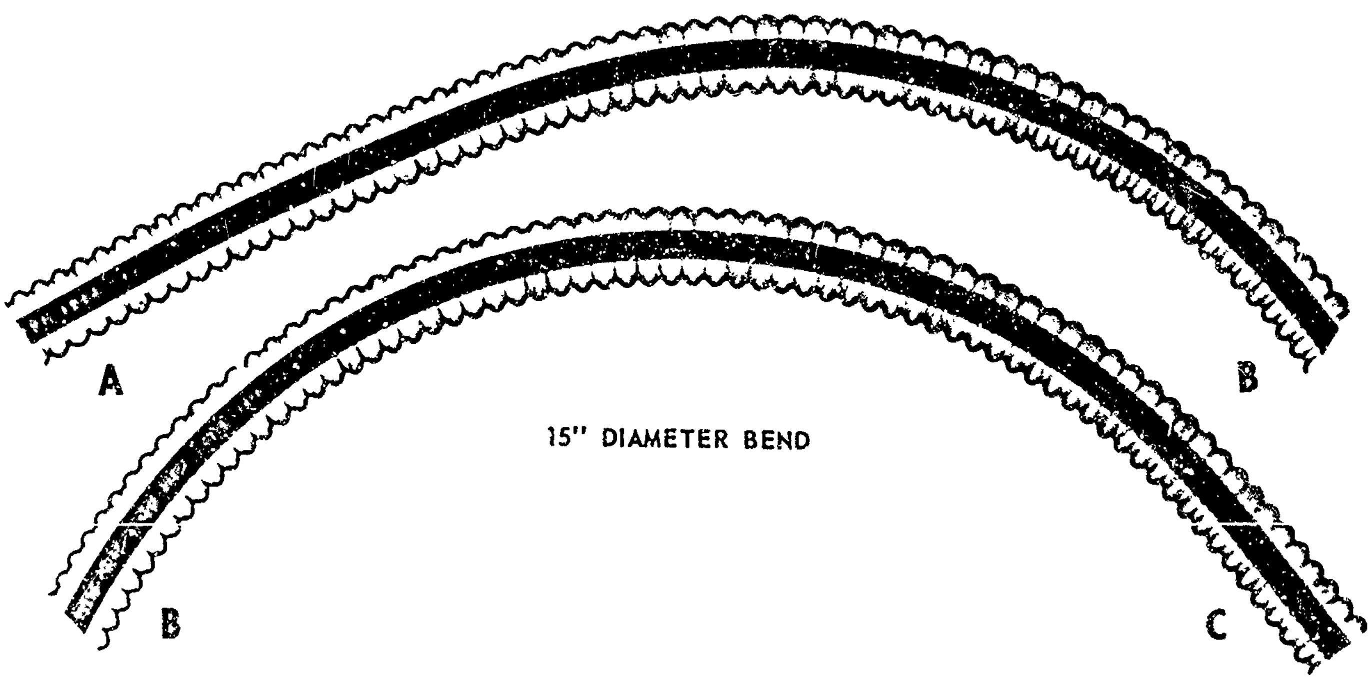
S.O. or E.P. No.
Type No.
Desc 7/8" H.T. HELIAX
Freq. 3000 to 5000 MC
Name
Date
CABLE "B"
VSWR of Prototype Cable No. 2 Shipped to ASD
10 Foot Length of 7/8" H. T. HELIAX with connectors
and Gas Barriers
VSWR
1.5
1.4
1.3
1.2
1.1
1.0
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
FREQUENCY MC/S

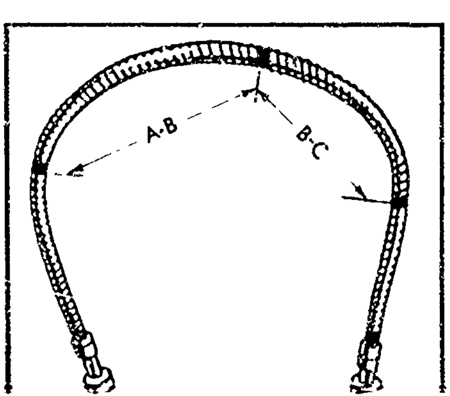
Figure 91.

CABLE "B"

VSWR AND BEND RADIUS TESTS





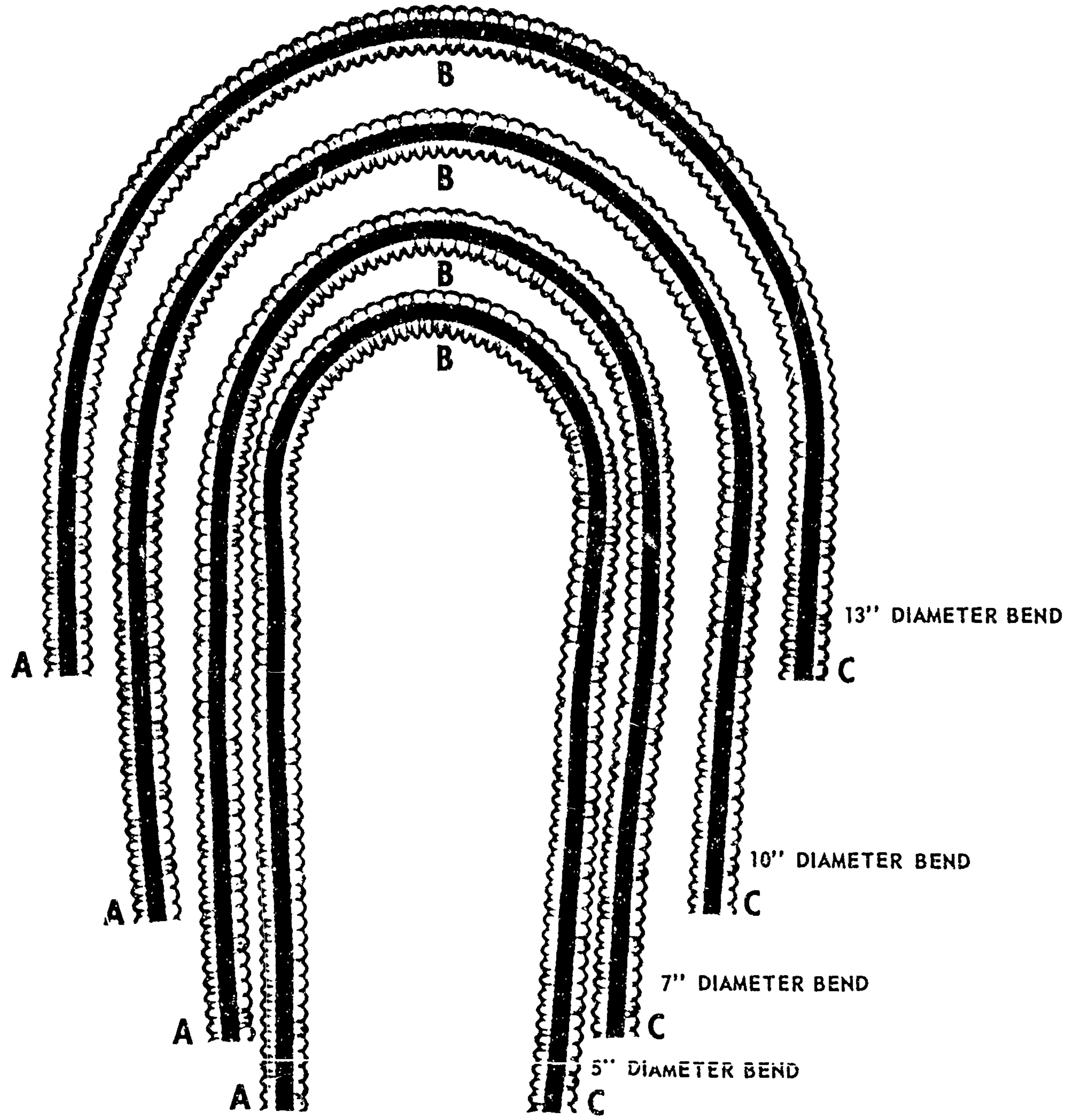


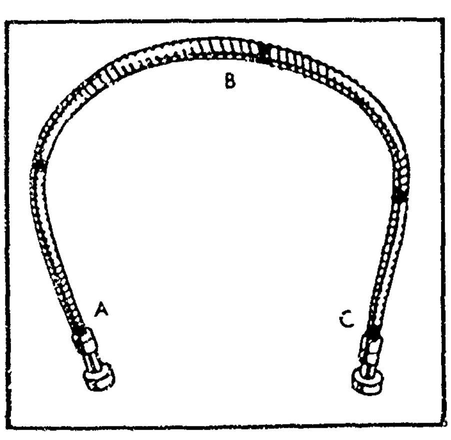
TEST CABLE
7/8'' HIGH TEMPERATURE
HELIAX

Figure 92.

CABLE "B"

VSWR AND BEND RADIUS TESTS





TEST CABLE

7/8" HIGH TEMPERATURE

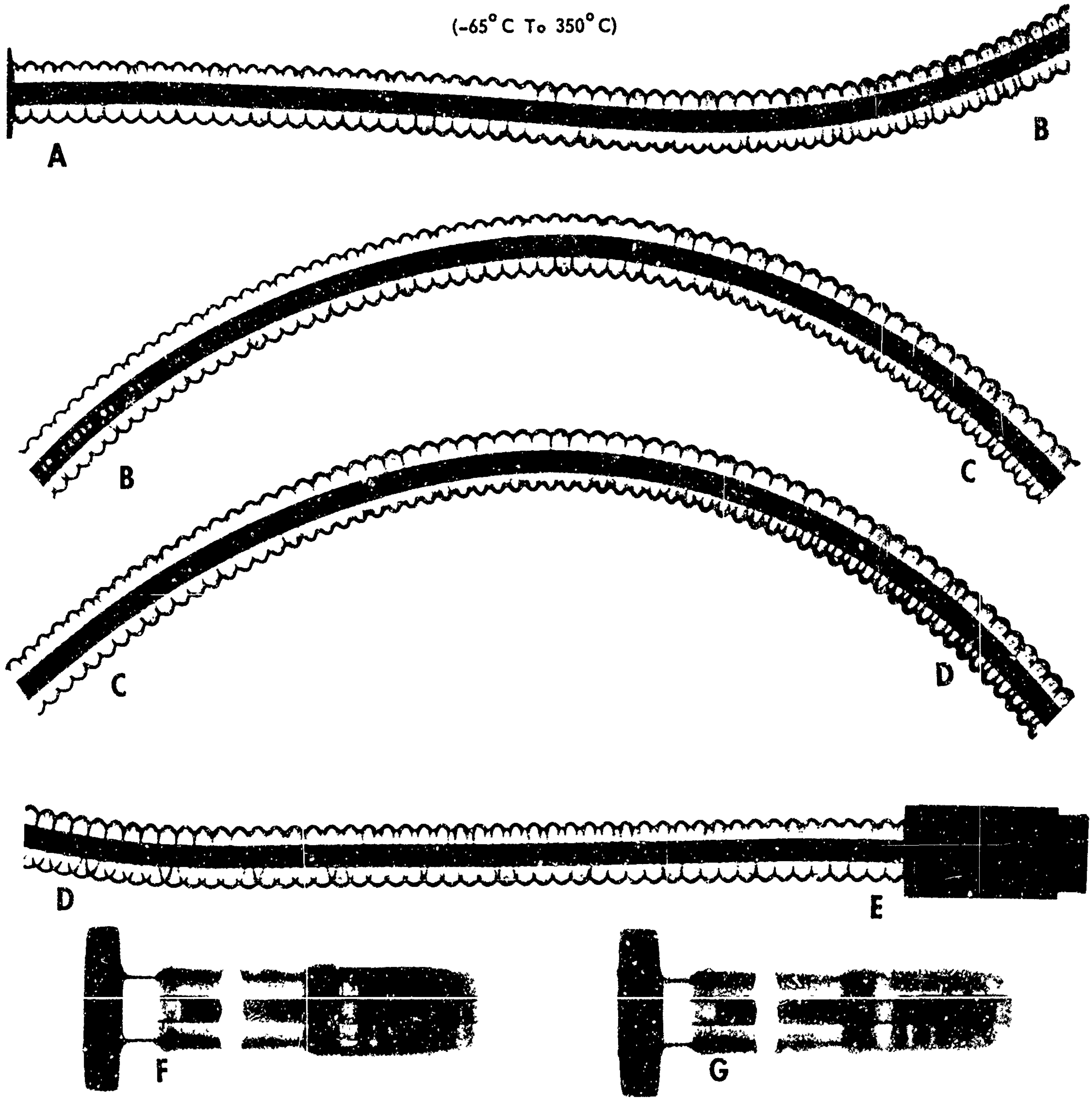
HELIAX

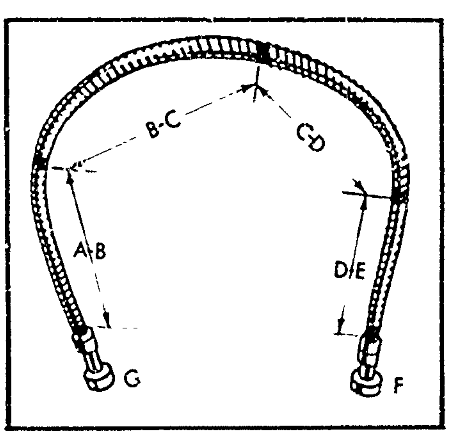
Figure 93.

CABLE "B"

AFTER 10 CYCLES OF THERMAL SHOCK

(-65° C To 350° C)





TEST CABLE NO. 1

7/8" HIGH TEMPERATURE

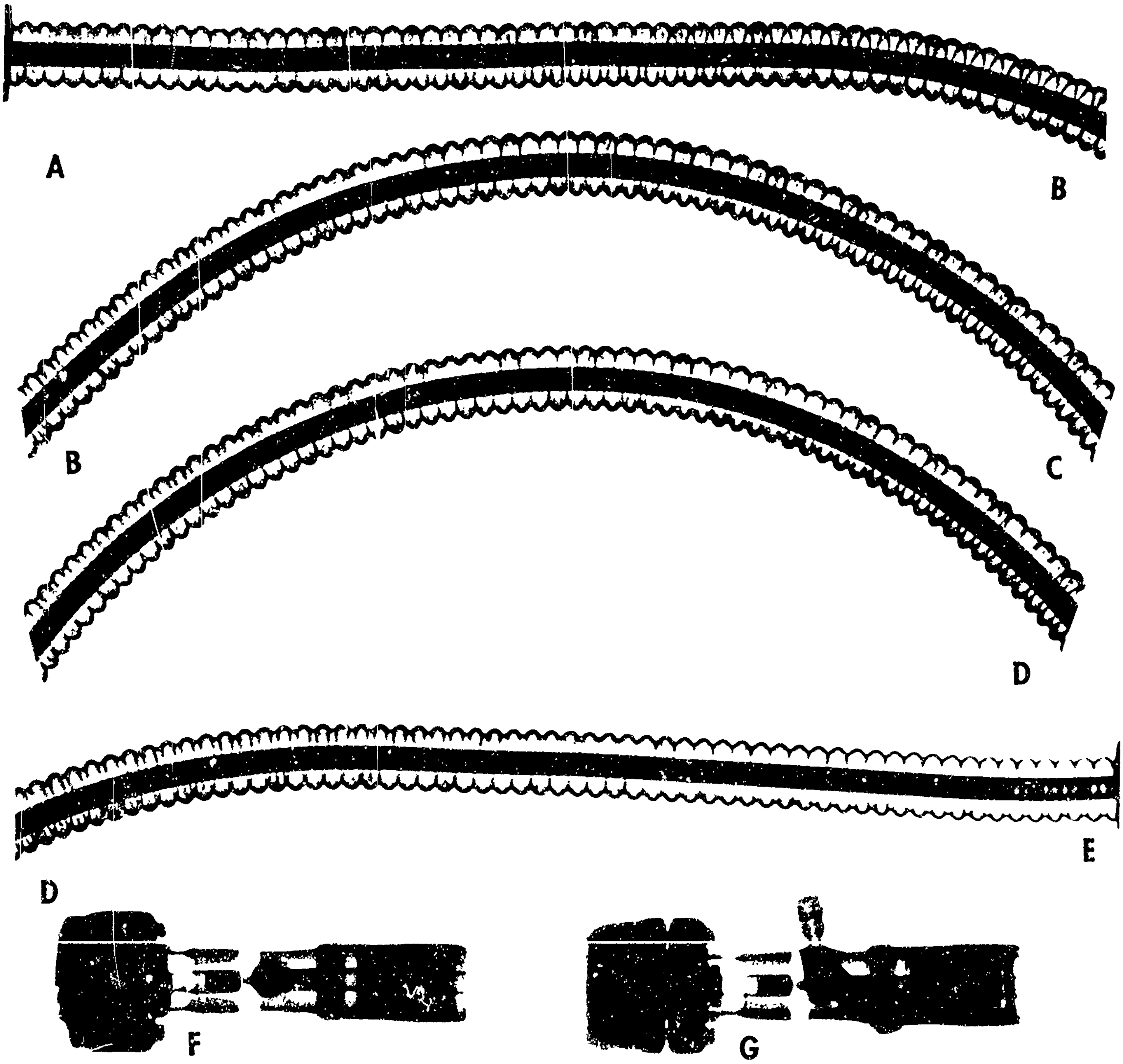
HELIAX

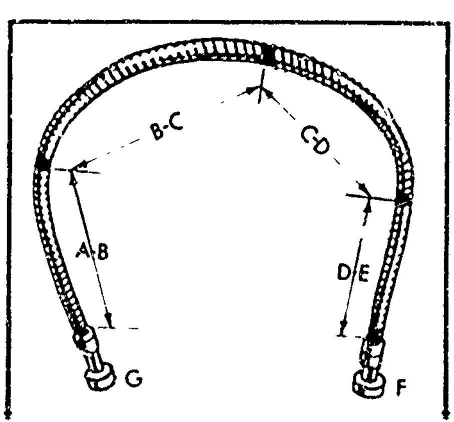
Figure 94.

CABLE "B"

AFTER 10 CYCLES OF THERMAL SHOCK

(-65° C To 350° C)





TEST CABLE NO. 2

7/8" HIGH TEMPERATURE

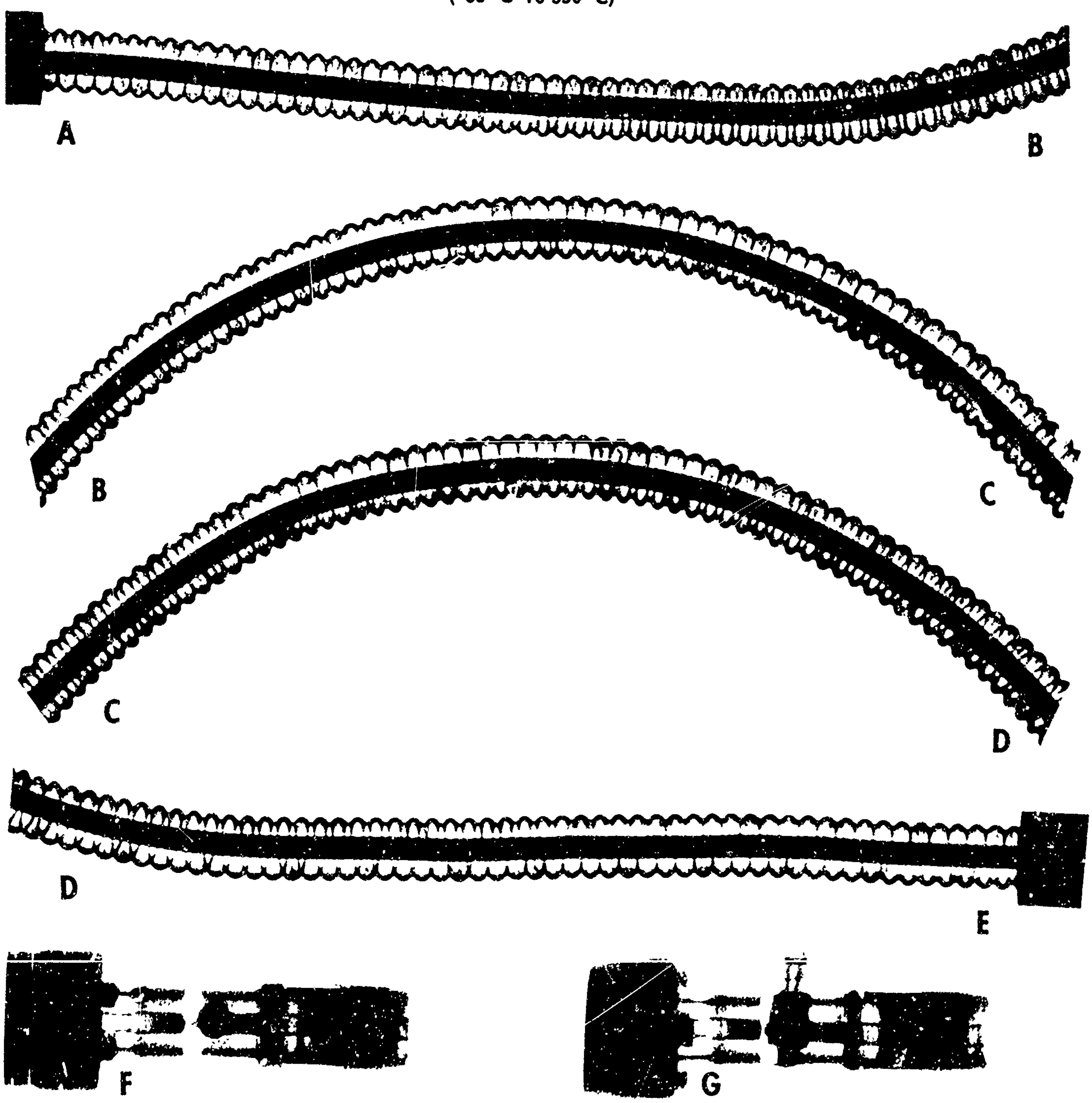
HELIAX

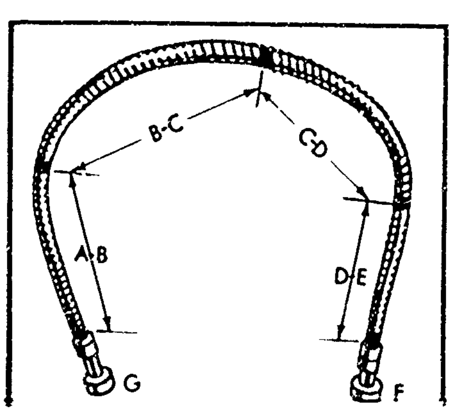
Figure 95.

CABLE "B"

AFTER 25 CYCLES OF THERMAL SHOCK

(-65° C To 350° C)





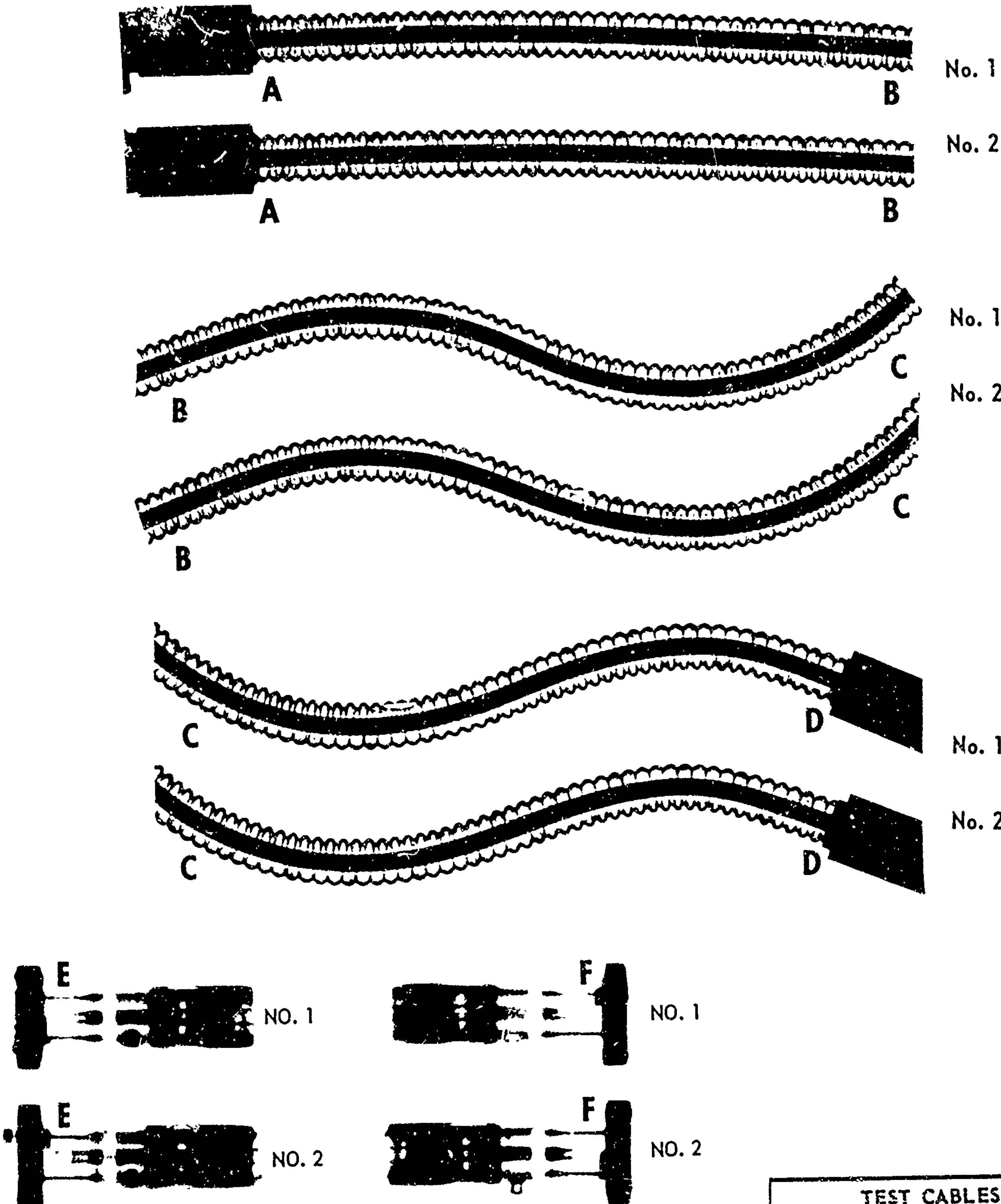
TEST CABLE NO. 2

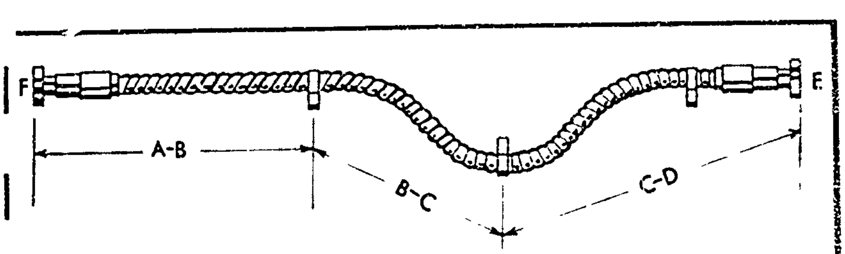
7/8" HIGH TEMPERATURE

Figure 96.

CABLE "B"

BEFORE VIBRATION TEST





TEST CABLES NO. 1 & 2

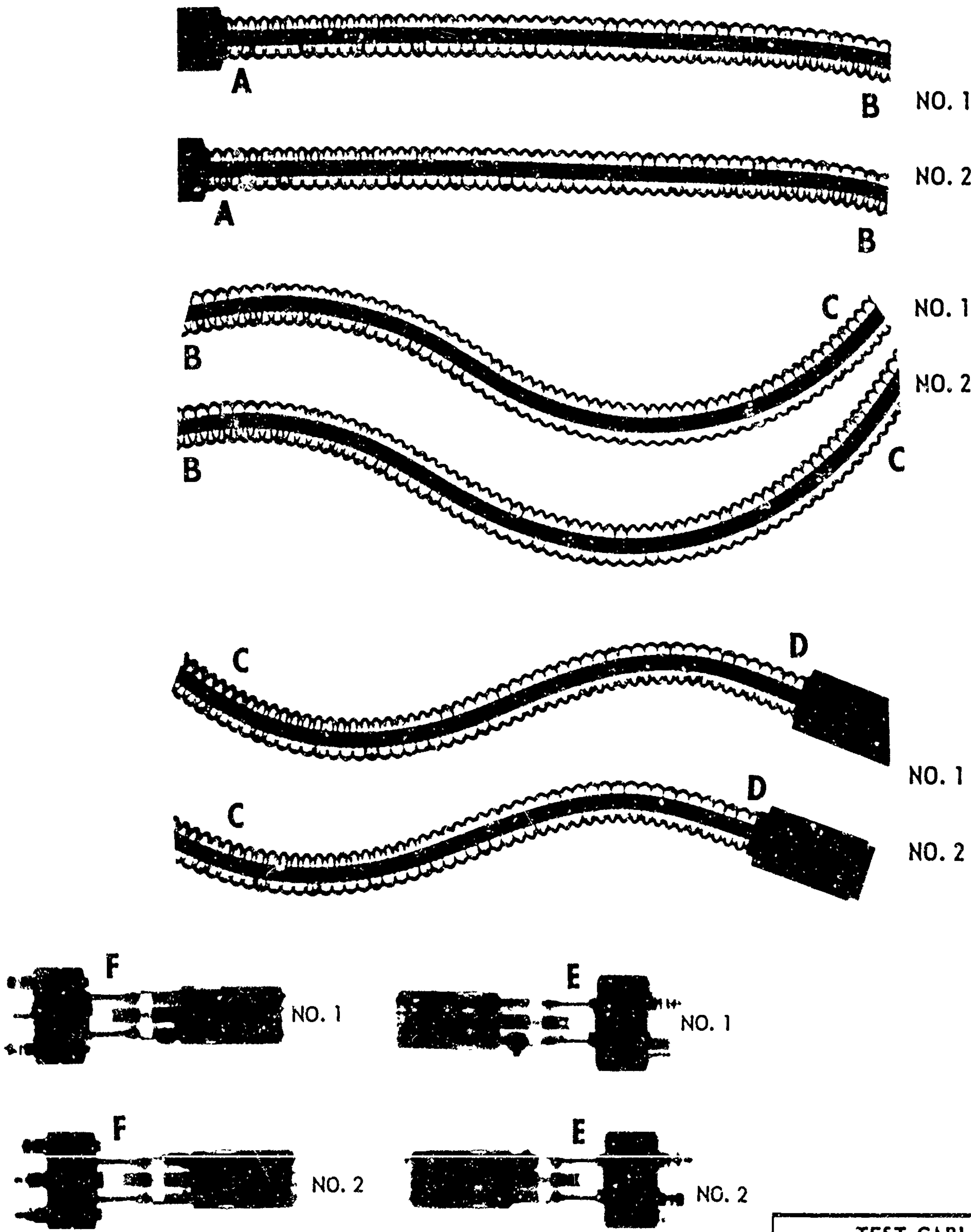
7/8" HIGH TEMPERATURE

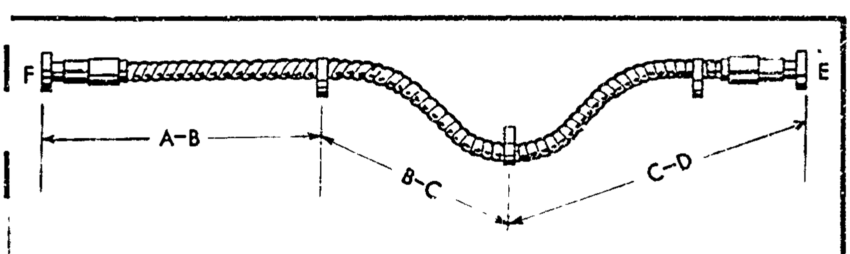
HELIAX

Figure 97.

CABLE "B"

AFTER VIBRATION TEST





TEST CABLES NO. 1 & 2

7/8" HIGH TEMPERATURE

HELIAX

Figure 98.

CABLE "A"

VSWR of two 3/8" H.T. Connectors - connected back-to-back.

S.C. or E.F. No

Type No

Desc 3/8" H.T. Connector

Freq 400-3000 MC/S

Name

Date

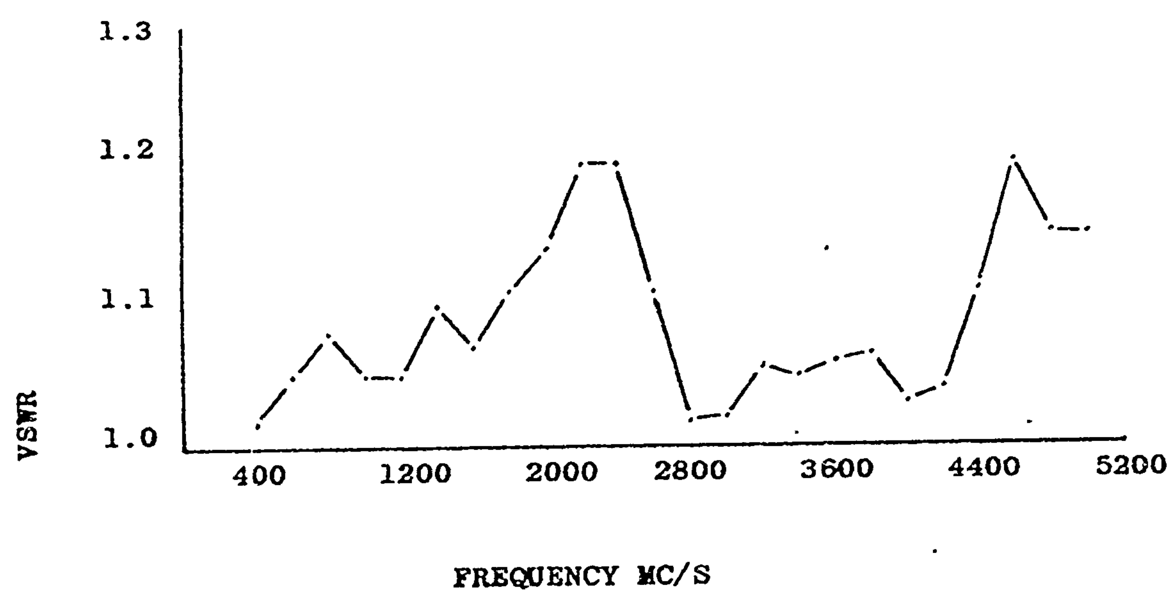
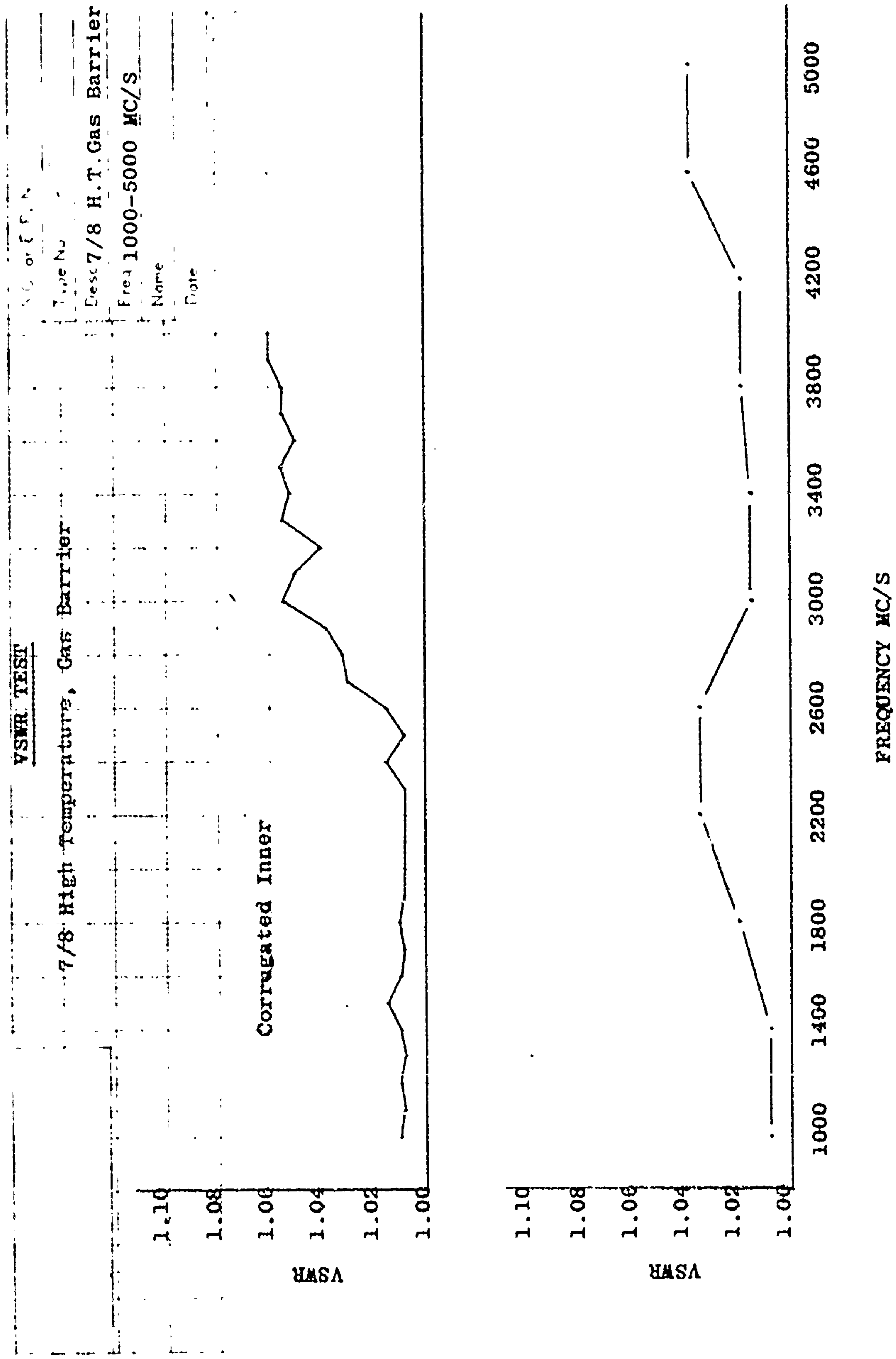


Figure 99.


VSWR TEST
7/8 High Temperature, Gas Barrier
Desc 7/8 H.T.Gas Barrier
Freq 1000-5000 MC/S
Type No
Name
Date
Corrugated Inner
VSWR
1.10
1.08
1.06
1.04
1.02
1.00
1000
1400
1800
2200
2600
3000
3400
3800
4200
4600
5000
FREQUENCY MC/S

CABLE "A"

Attenuation of 3/8" High Temperature HELIAX

<u>Room Temperature 20°C</u>

3/8" H.T. HELIAX
400-5000 MC

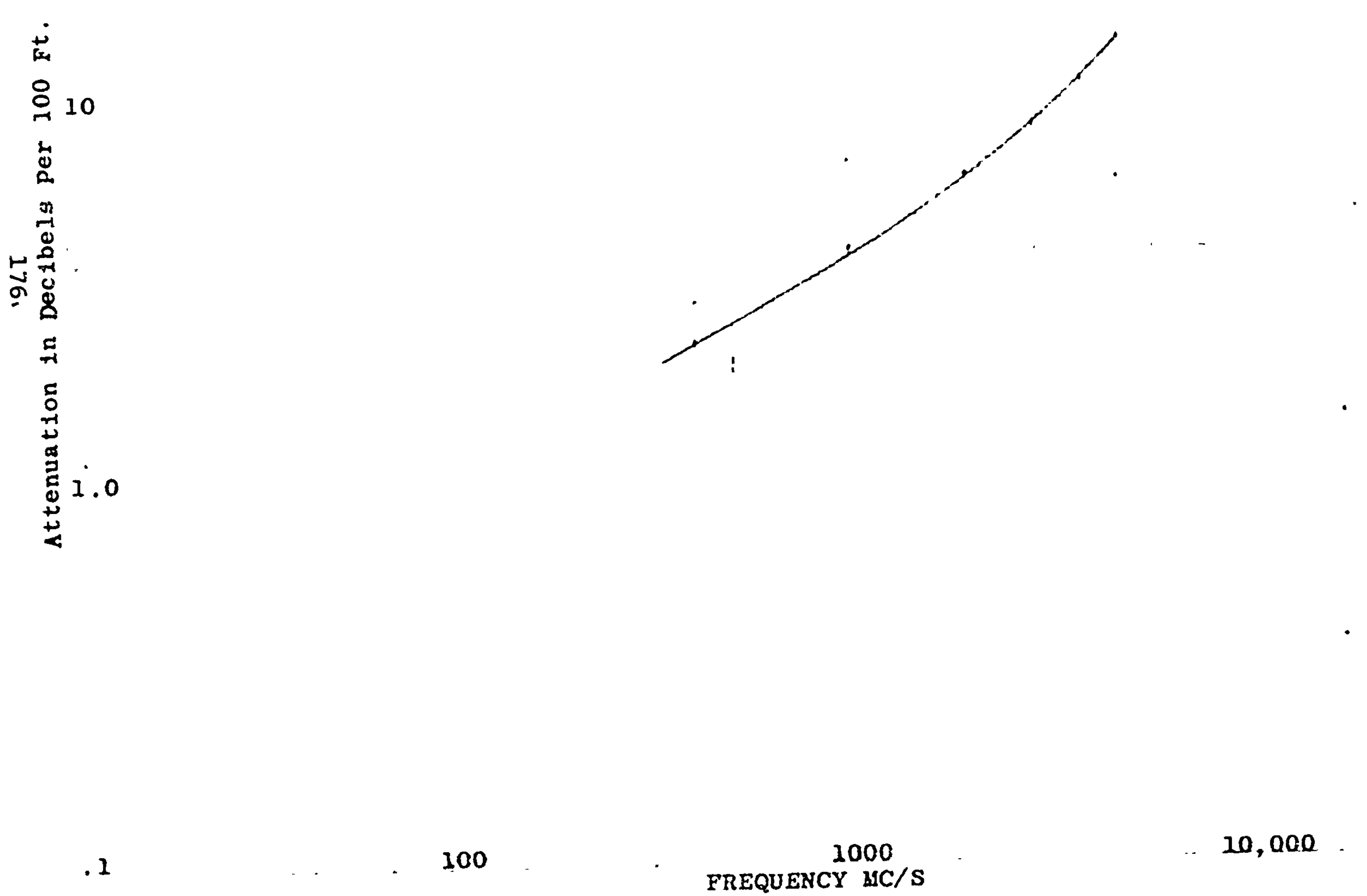


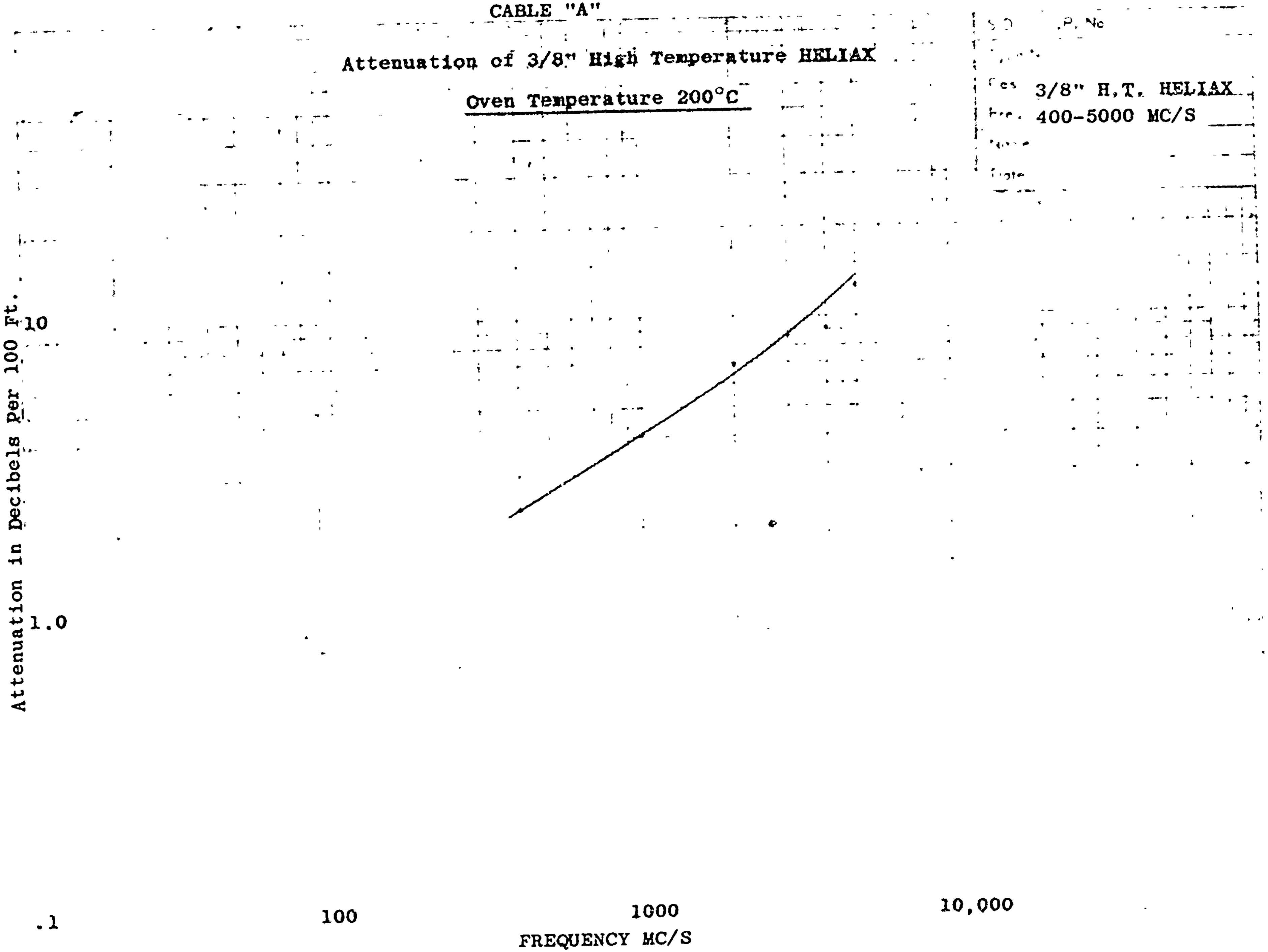
Figure 100.

Figure 101.

CABLE "A"

Attenuation of 3/8" High Temperature HELIAX

Oven Temperature 200°C



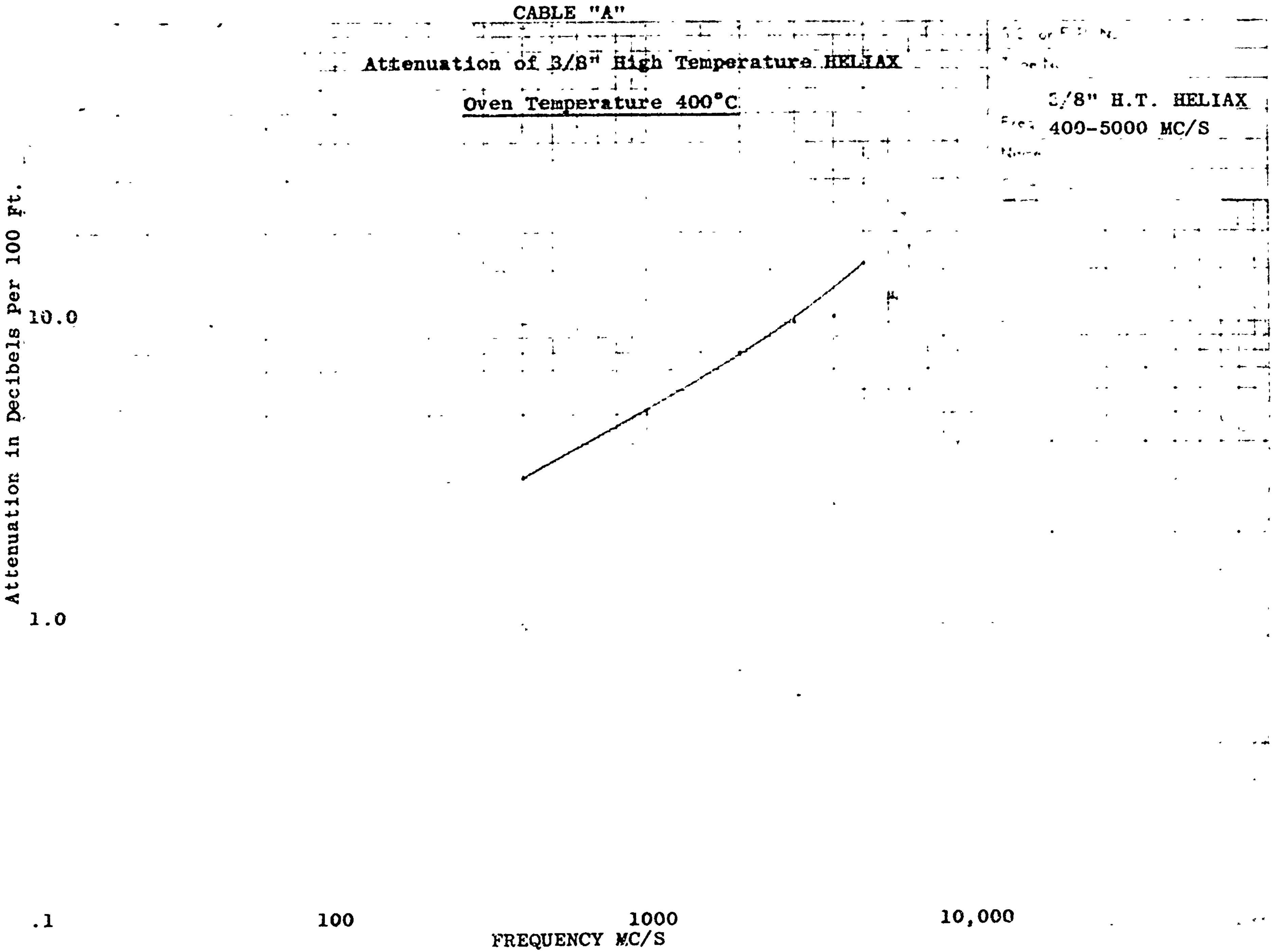

CABLE "A"
Attenuation of 3/8" High Temperature HELIAX
Oven Temperature 400°C
3/8" H.T. HELIAX
400-5000 MC/S
Attenuation in Decibels Per 100 Ft.
10.0
1.0
.1
100
1000
10,000
FREQUENCY MC/S

Figure 102.

CABLE "A"

Attenuation of 3/8" High Temperature HELIAX

Oven Temperature 600°C

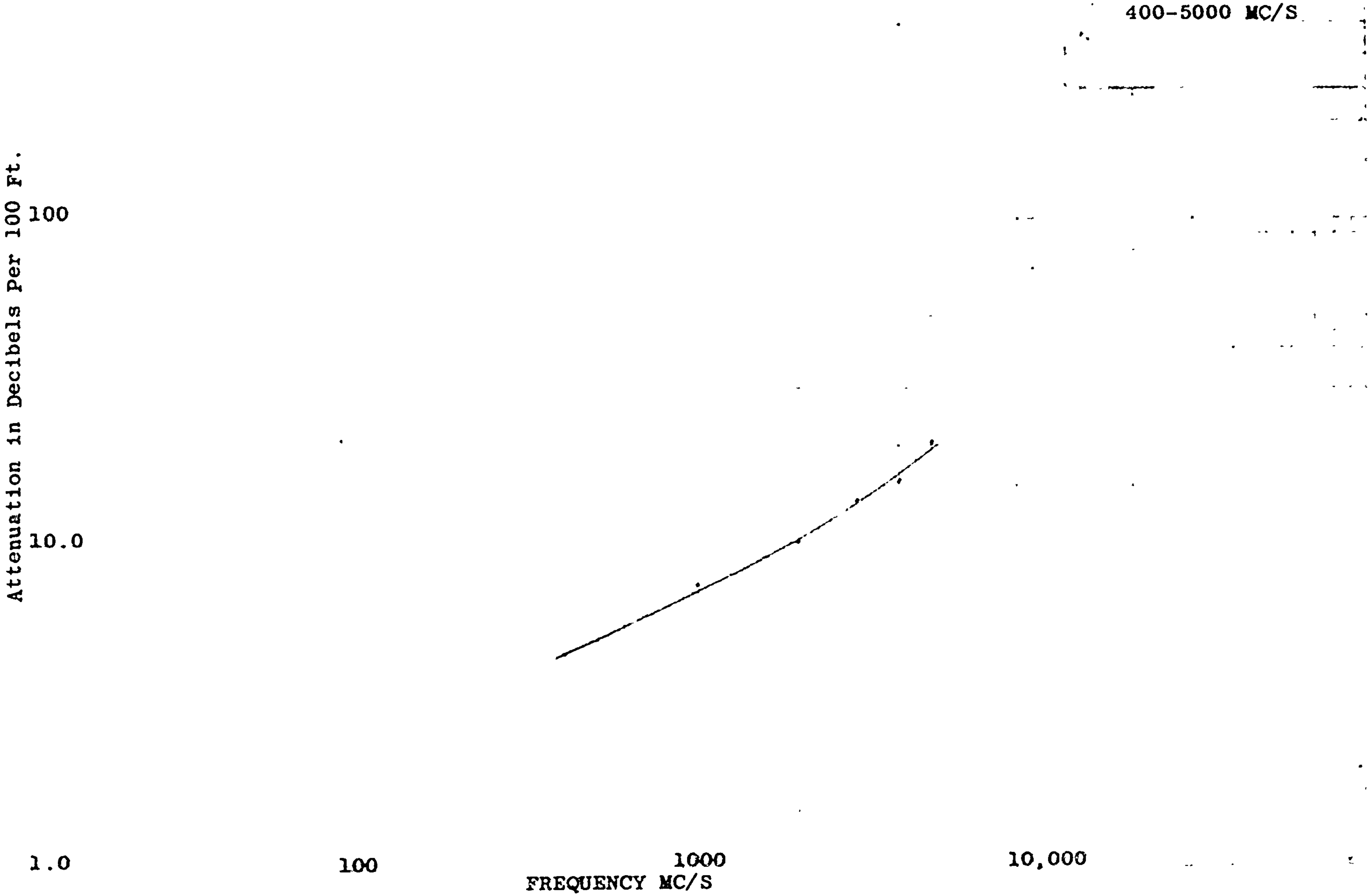


Figure 103.

Figure 104.

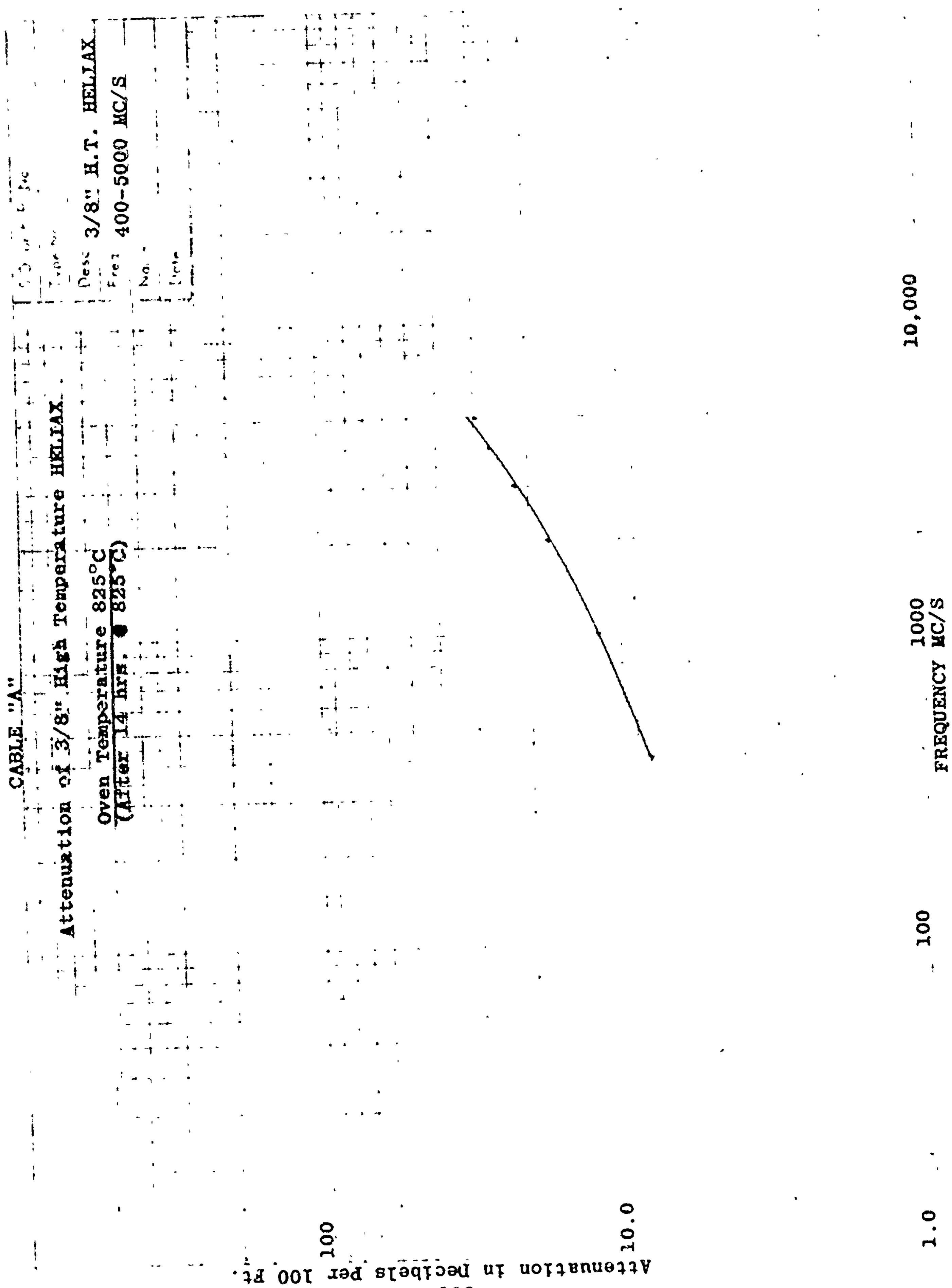
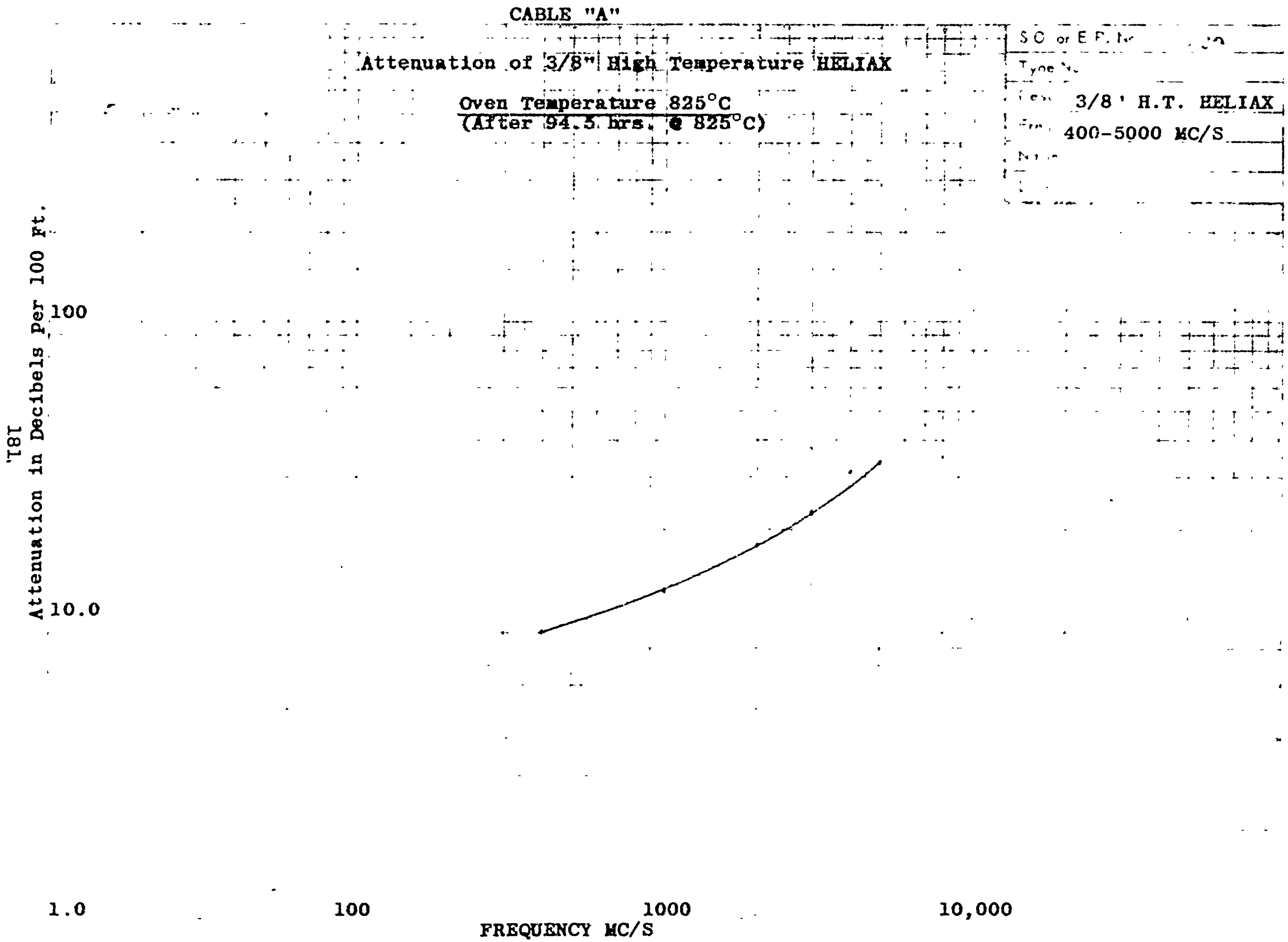
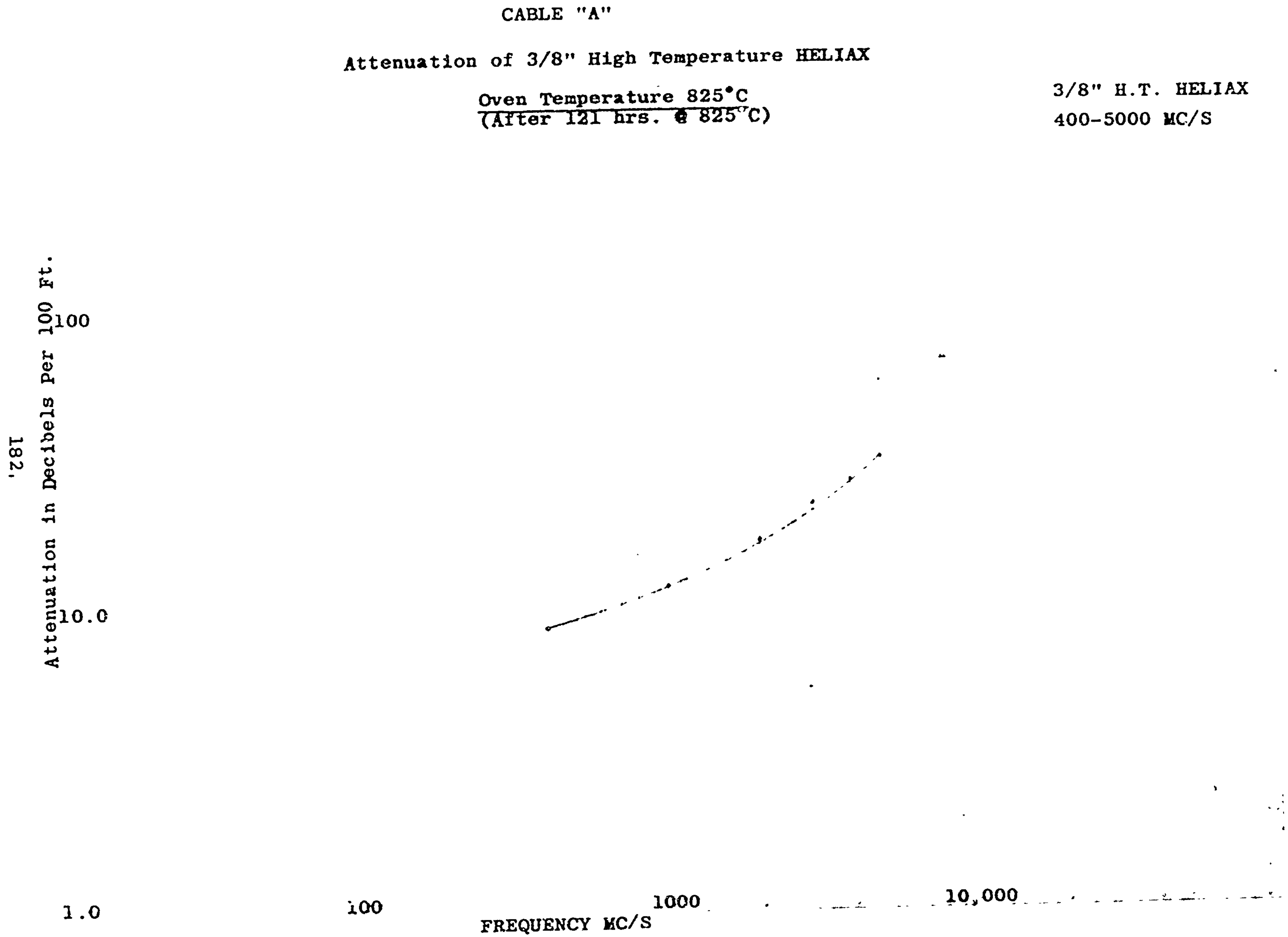

CABLE "A"
Attenuation of 3/8" High Temperature HELIAX
Oven Temperature 825°C
(After 14 hrs. @ 825°C)
Desc 3/8" H.T. HELIAX
Freq 400-5000 MC/S
100
10.0
1.0
100
1000
10,000
FREQUENCY MC/S
Attenuation in Decibels per 100 Ft.

Figure 105.



CABLE "A"
Attenuation of 3/8" High Temperature HELIAX
Oven Temperature 825°C
(After 94.5 hrs. @ 825°C)
3/8' H.T. HELIAX
400-5000 MC/S
100
10.0
Attenuation in Decibels Per 100 Ft.
1.0
100
1000
10,000
FREQUENCY MC/S


CABLE "A"
Attenuation of 3/8" High Temperature HELIAX
Oven Temperature 825°C
(After 121 hrs. @ 825°C)
3/8" H.T. HELIAX
400-5000 MC/S
Attenuation in Decibels Per 100 Ft.
100
10.0
1.0
100
1000
10,000
FREQUENCY MC/S
Figure 106.

CABLE "A"

Attenuation of 3/8" High Temperature HELIAX

Oven Temperature 825°C
(After 185 hrs. @ 825°C)

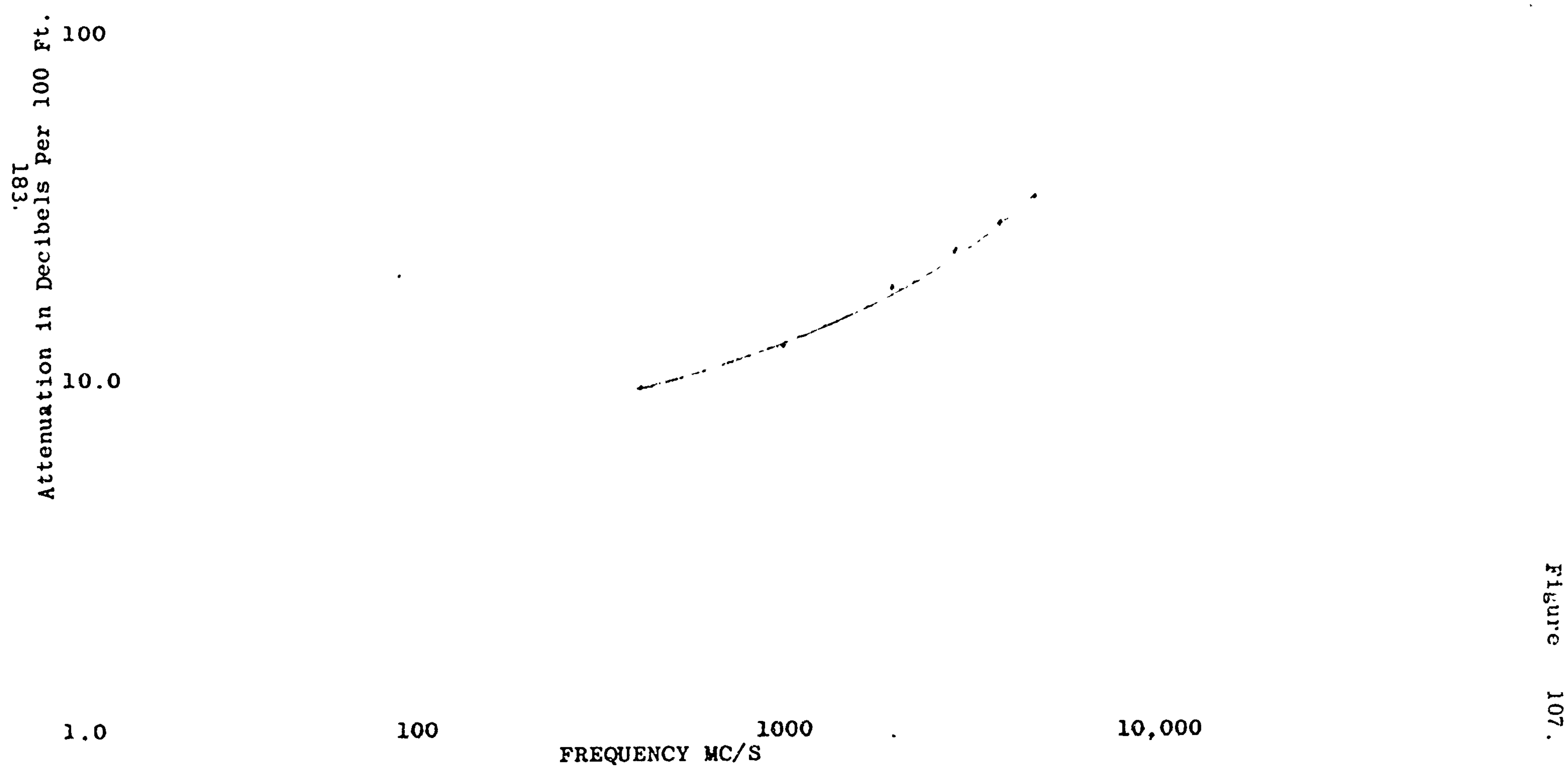
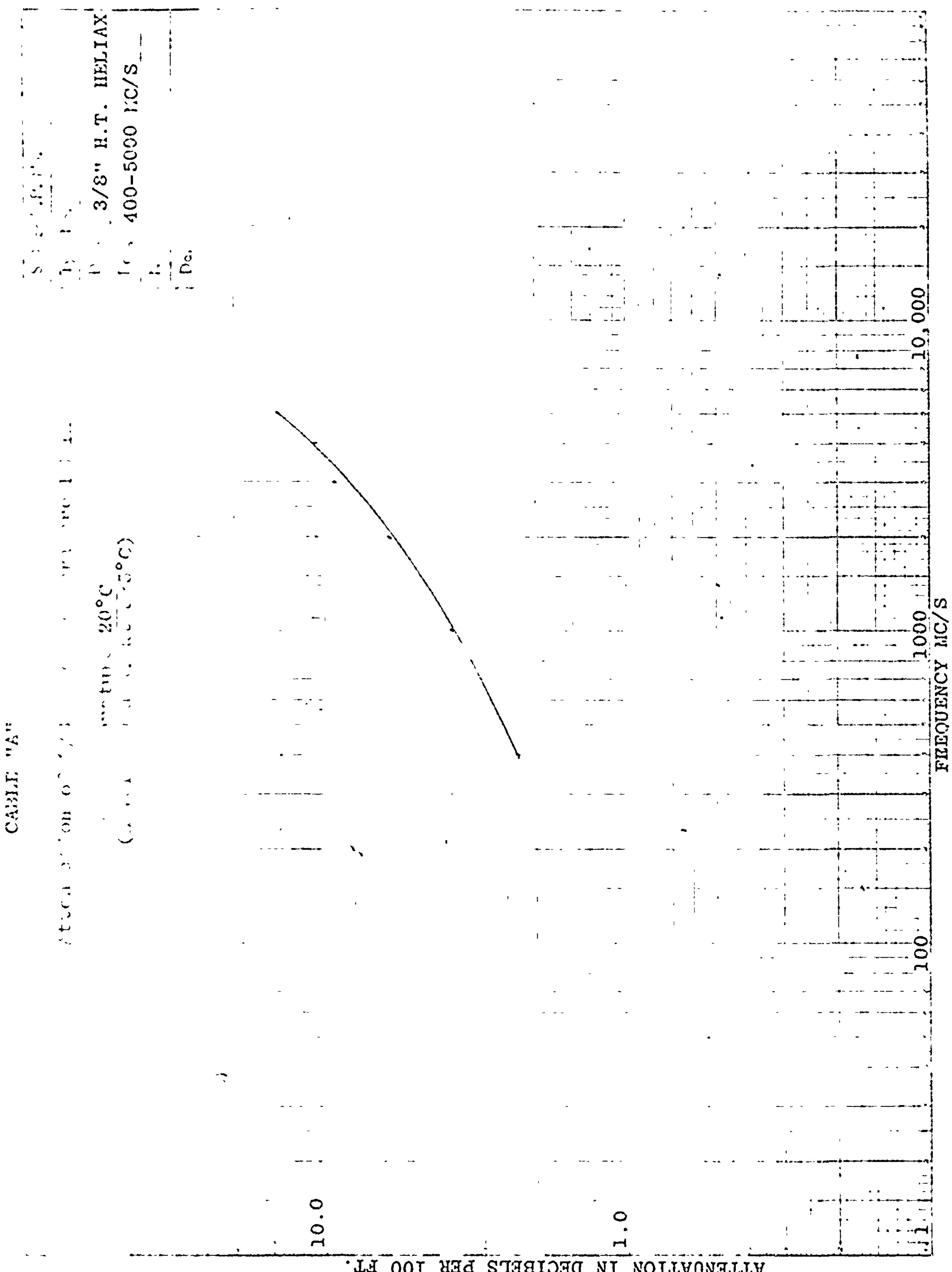


Figure 107.

Figure 108.



CABLE "A"
3/8" H.T. HELIAX
400-5000 MC/S
20°C
FREQUENCY MC/S
10,000
1000
100
10.0
1.0
ATTENUATION IN DECIBELS PER 100 FT.

CABLE "A"

Attenuation of 3/8" High Temperature HELIAX

50 Foot Length

(Final Prototype Cable)

Room Temperature 20°C

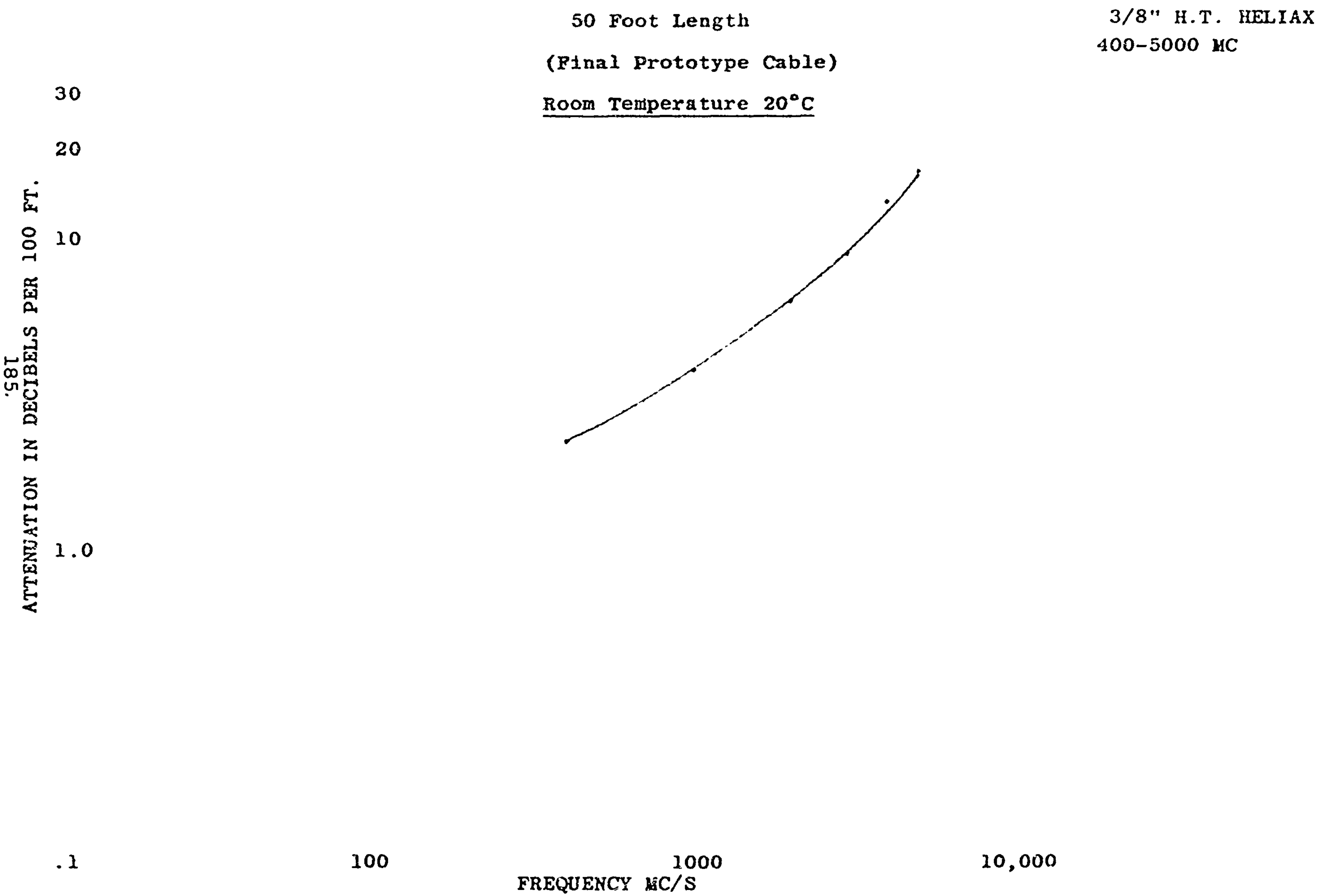
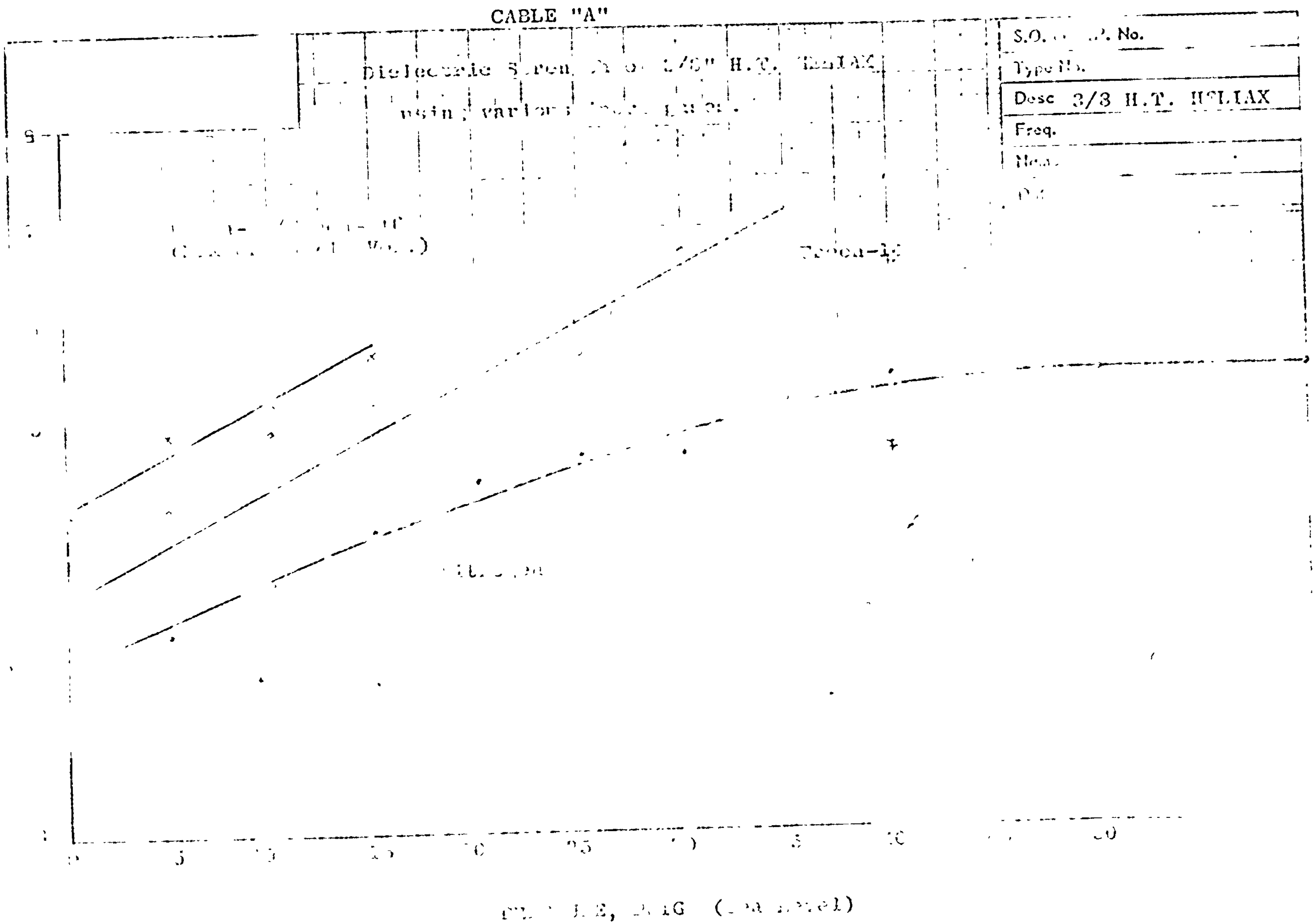


Figure 108 a.


CABLE "A"
S.O.
No.
Desc 3/3 H.T.
Freq.

CABLE "A"

VSWR of a 10 Foot Length of 3/8" H.T. HELIAX
with connectors

Straight Length

S.O. or E.F. No.
Type No.
Desc. 3/8" H.T. HELIAX
Freq. 600 to 3000 MC
Name
Date

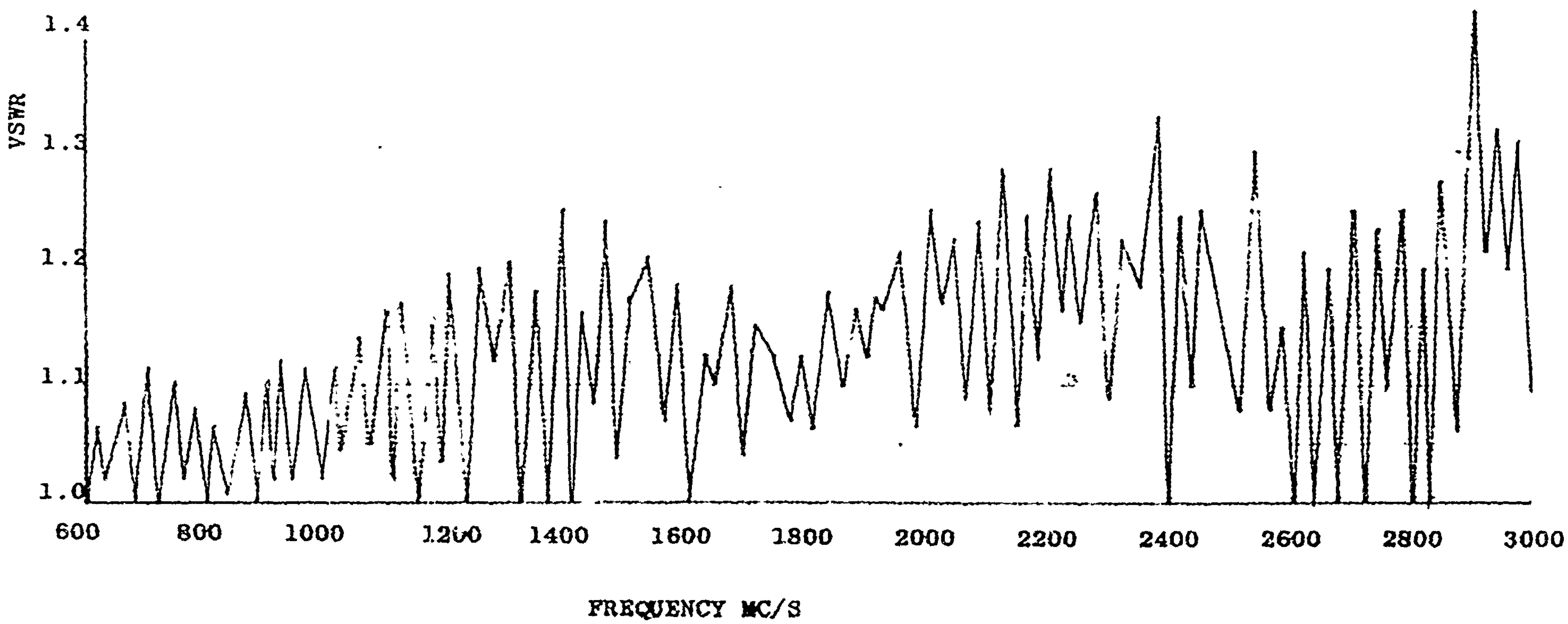


Figure 110.

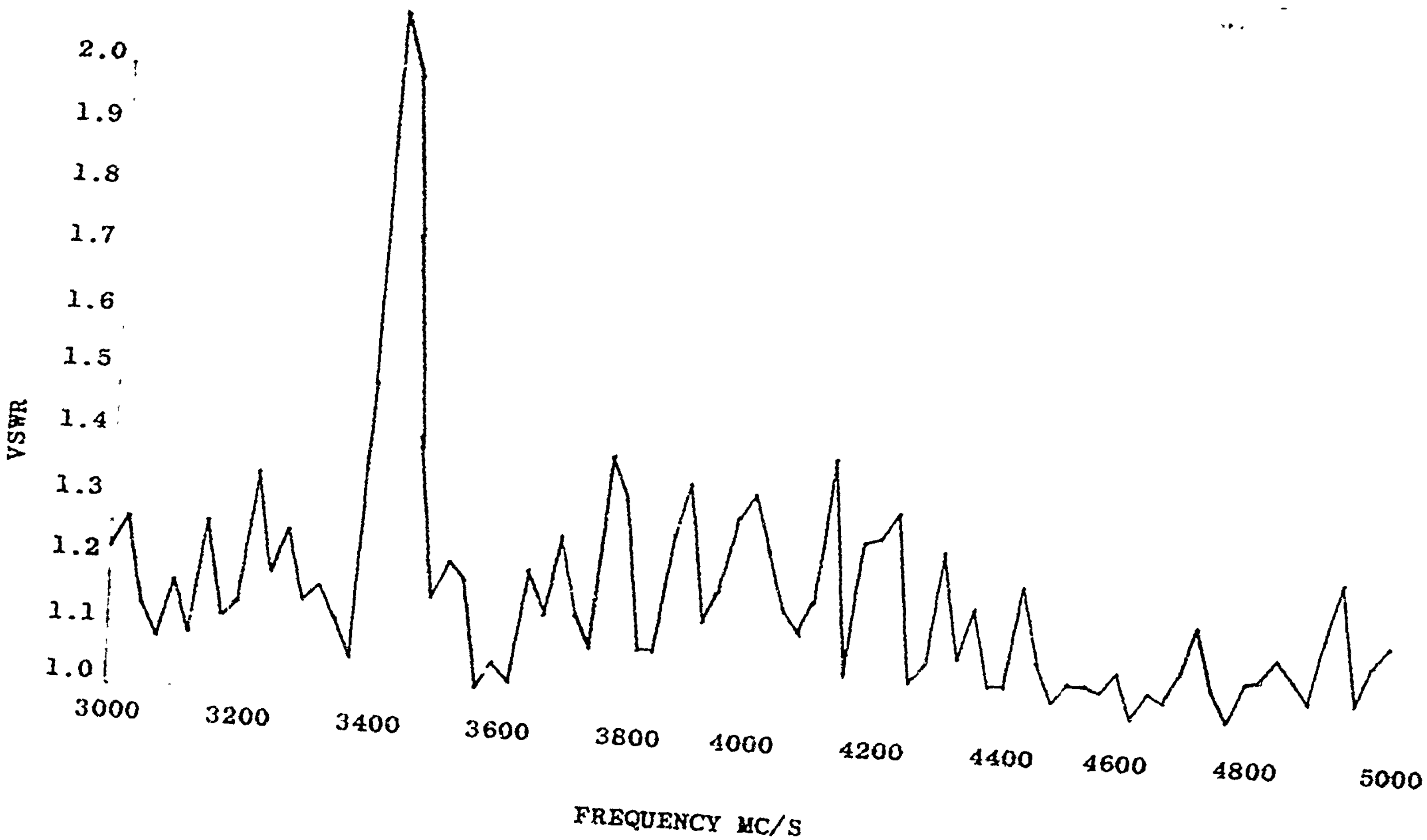
Figure 111.

CABLE "A"

VSWR of a 10 Foot Length of 3/8"
H.T. HELIAX with Connectors

Straight Length

3/8" H.T. HELIAX
3000-5000 MC



CABLE "A"

VSWR of a 10 Foot length of 3/8" H.T. Cable with connectors

10" Diameter Bend

3/8" H.T. HELIAX

600 to 5000 MC

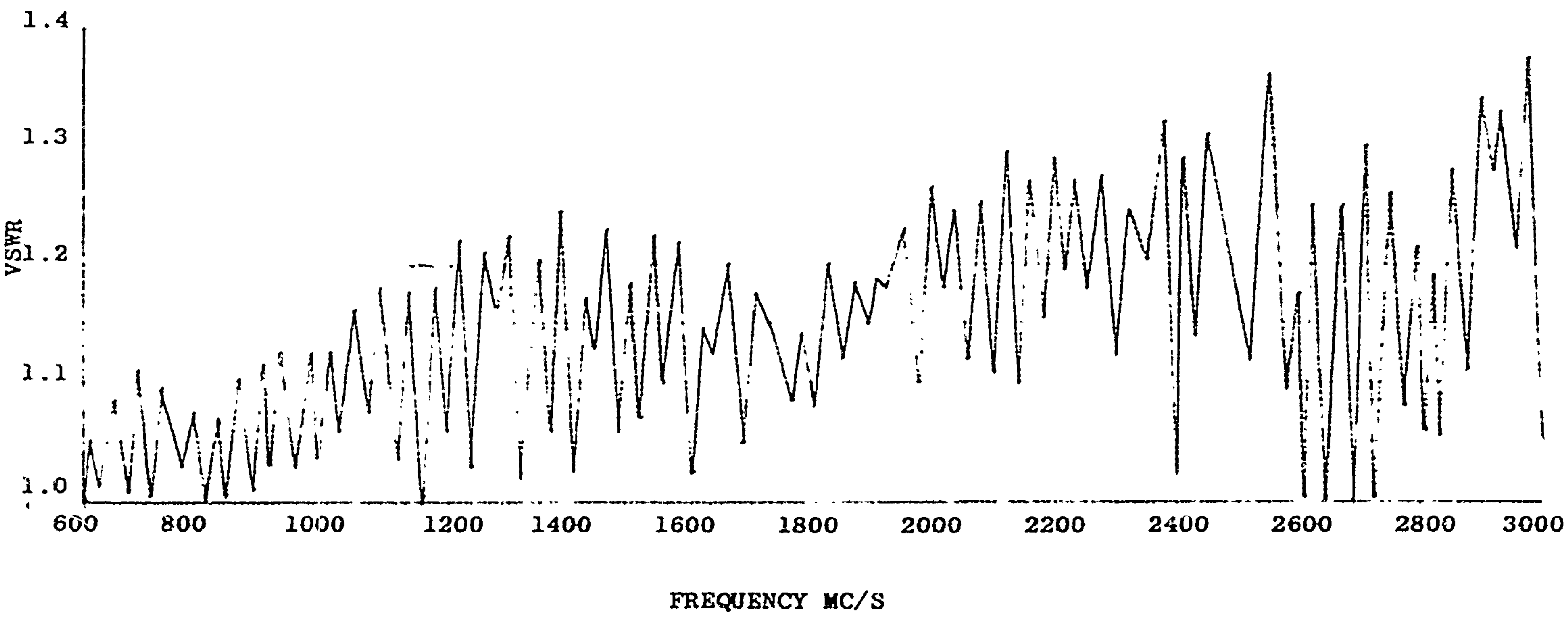


Figure 112.

CABLE "A"

VSWR of a 10 Foot length of 3/8" H.T. HELIAX with connectors.

10" Diameter Bend

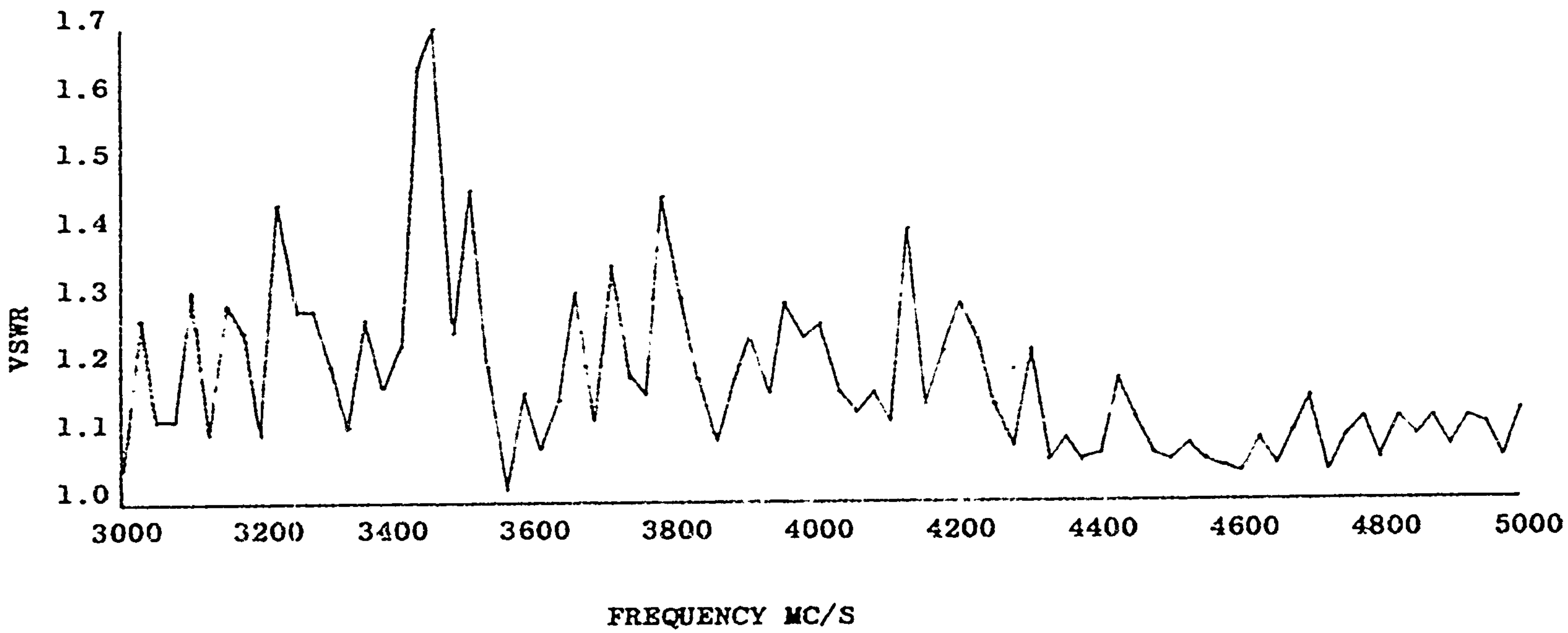


Figure 113.

CABLE "A"

VSWR of a 10 Foot Length of 3/8" H.T. HELIAX
with connectors

6-1/2" Diameter Bend

3/8" H.T. HELIAX
600 - 3000MC

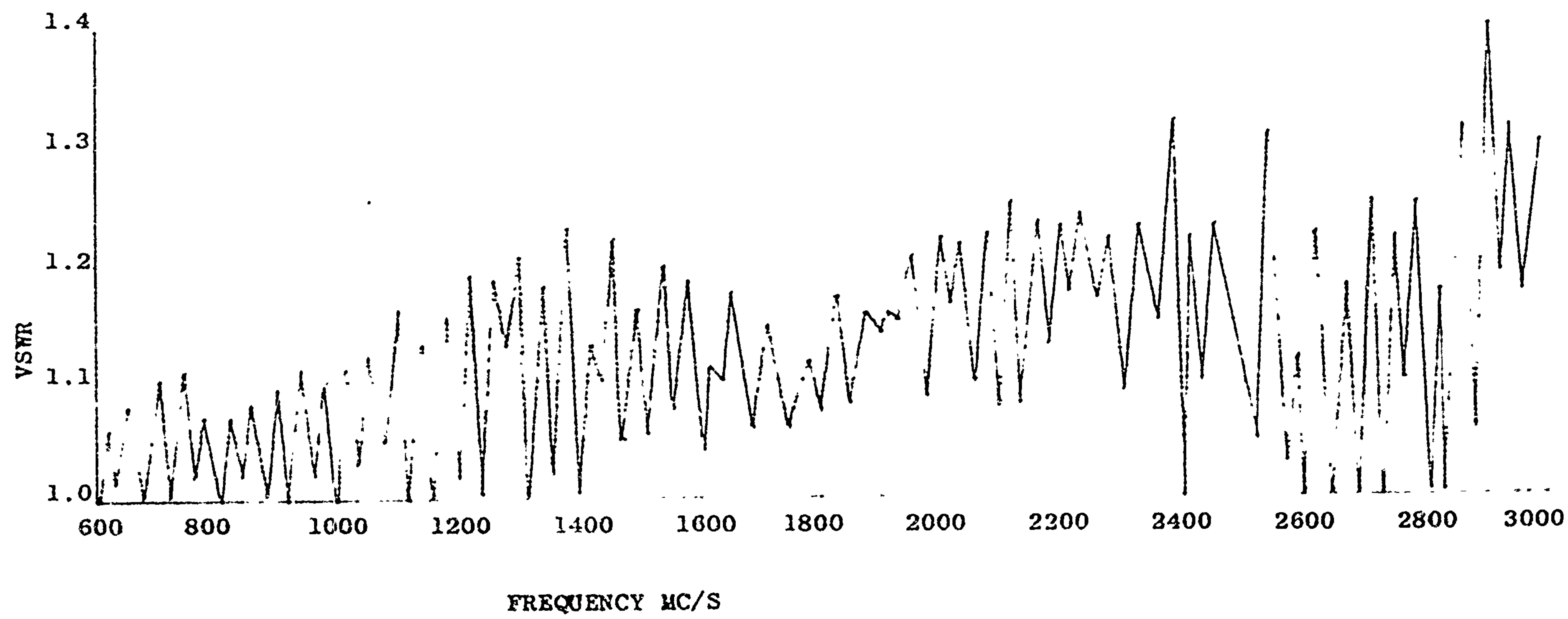


Figure 114.

CABLE "A"

VSWR of a 10 Foot Length of 3/8" H.T. HELIAX
with connectors

<u>4-1/2" Diameter Bend</u>

3/8" H.T. HELIAX

600 - 3000 MC

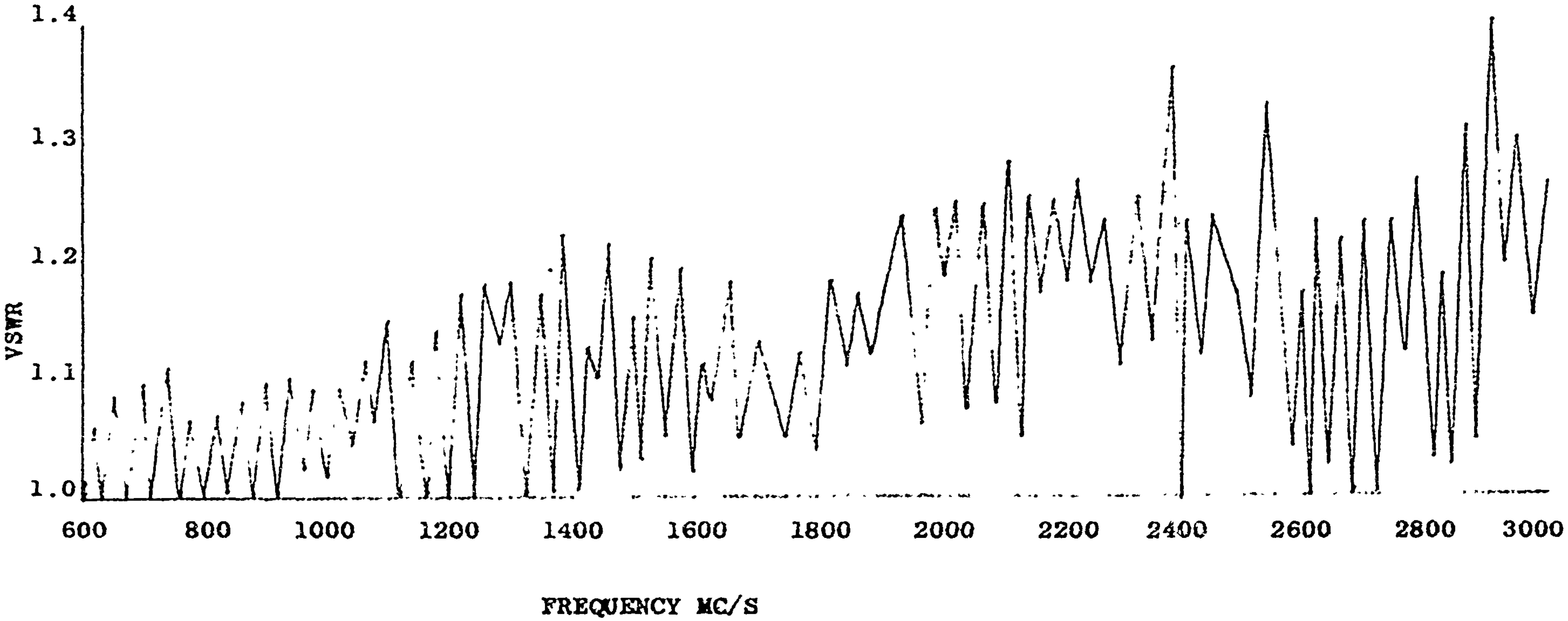


Figure 115.

CABLE "A"

VSWR of a 10 Foot Length of 3/8" H.T. HELIAX
with connectors

3-1/2" diameter Bend

3/8" H.T. HELIAX
600 - 3000 MC

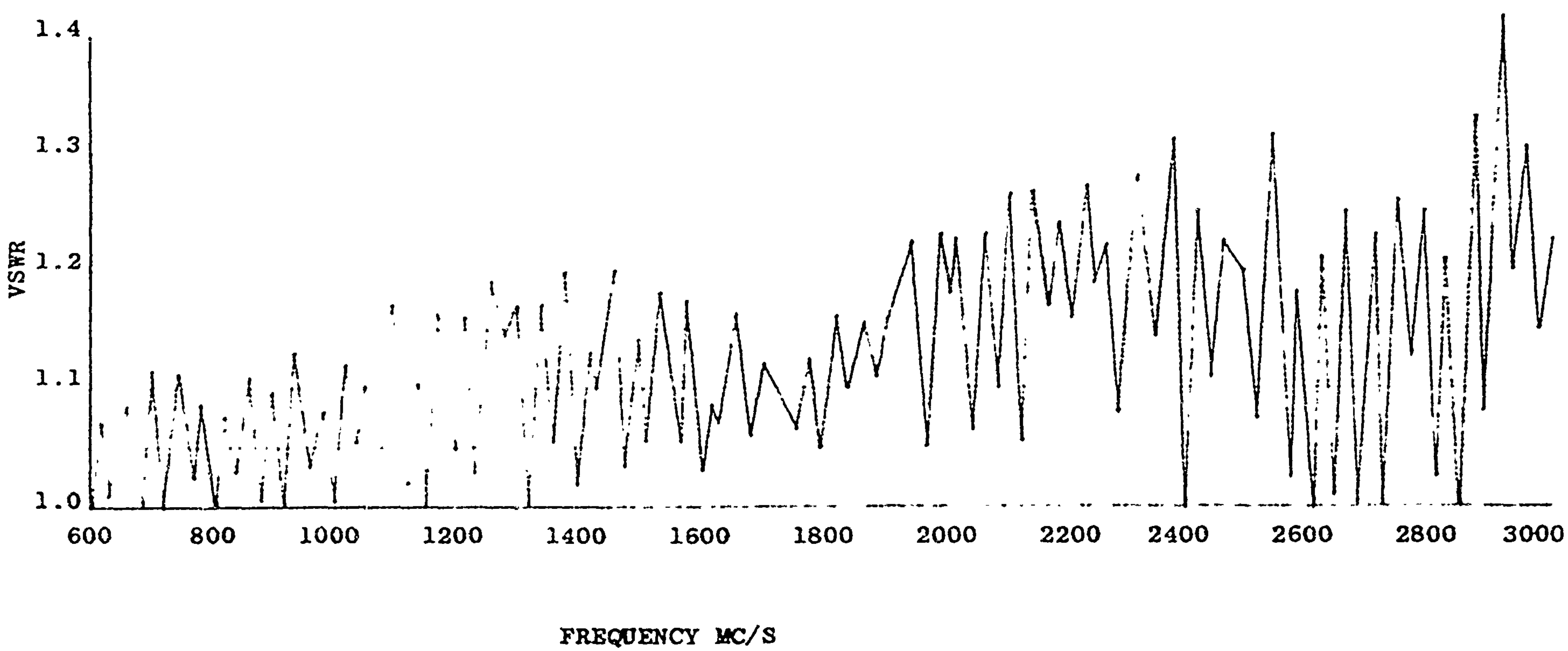
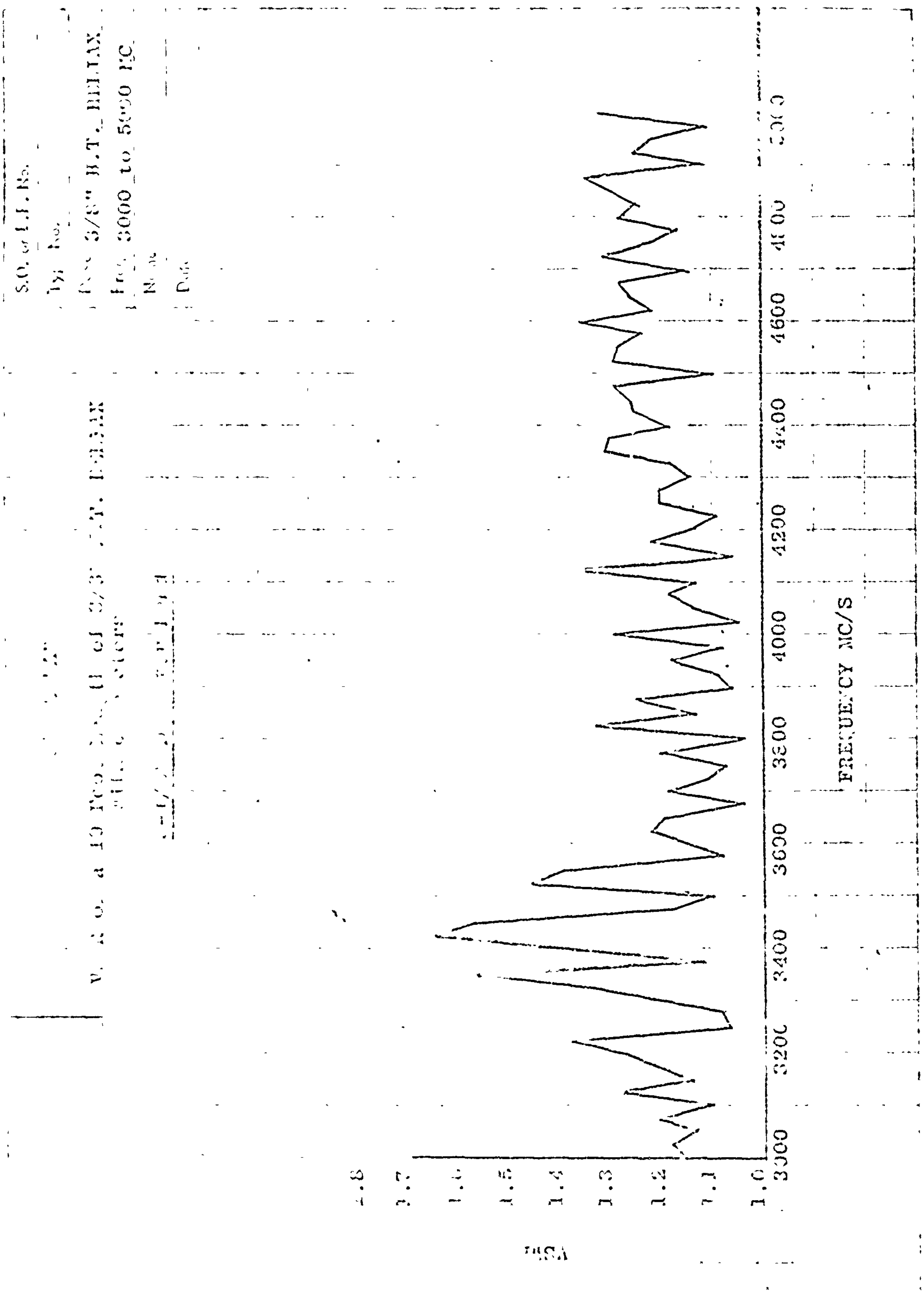


Figure 116.

Figure 117.



CABLE "A"

VSWR of a 5 Foot Length of 3/8" H.T. HELIAX
with connectors

VSWR after 3 cycles of thermal shock

Desc 3/8" H.T. HELIAX
Freq 600 to 3000 MC

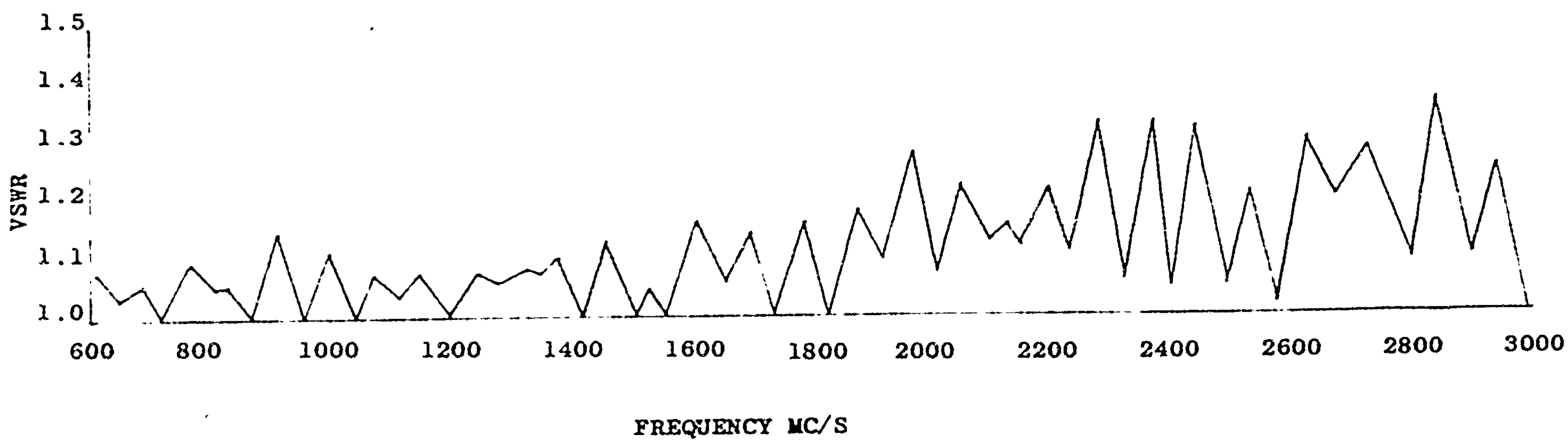


Figure 118.

CABLE "A"

VSWR of a 5 Foot Length of 3/8" H.T. HELIAX
with connectors

VSWR after 5 cycles of thermal shock

3/8" H.T. HELIAX
600 to 3000 MC

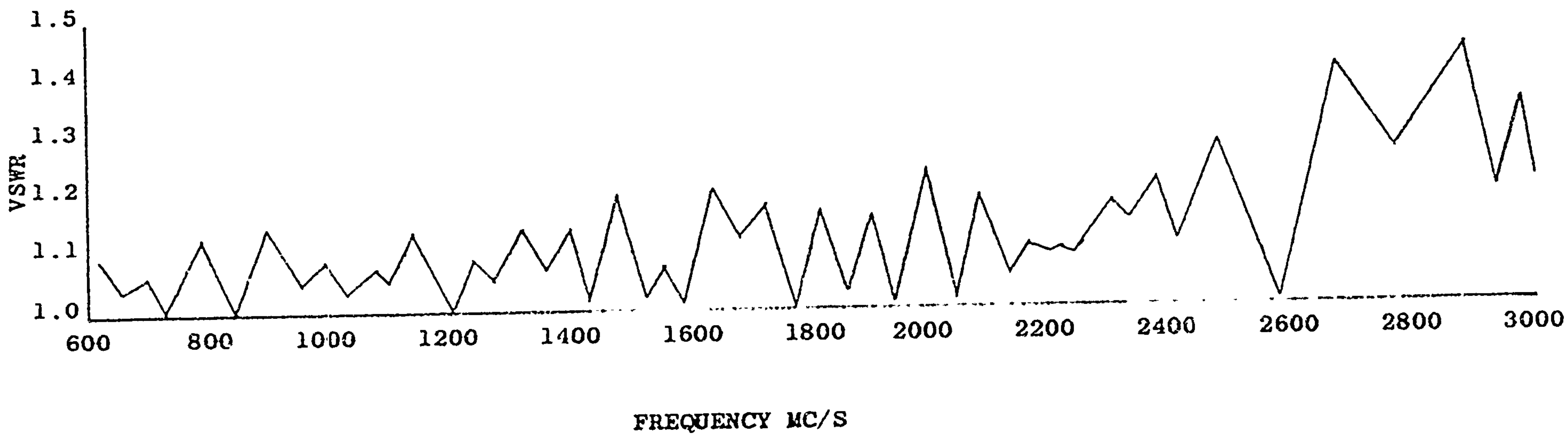


Figure 119.

CABLE "A"

3/8" H.T. HELIAX Bent for Vibration Tests (See Test Procedure Par. 4.5.11)

VSWR Before Vibration Tests
Cable No. 1

Type No.
Desc. 3/8" H.T. HELIAX
Freq. 600 to 5000 MC
Name

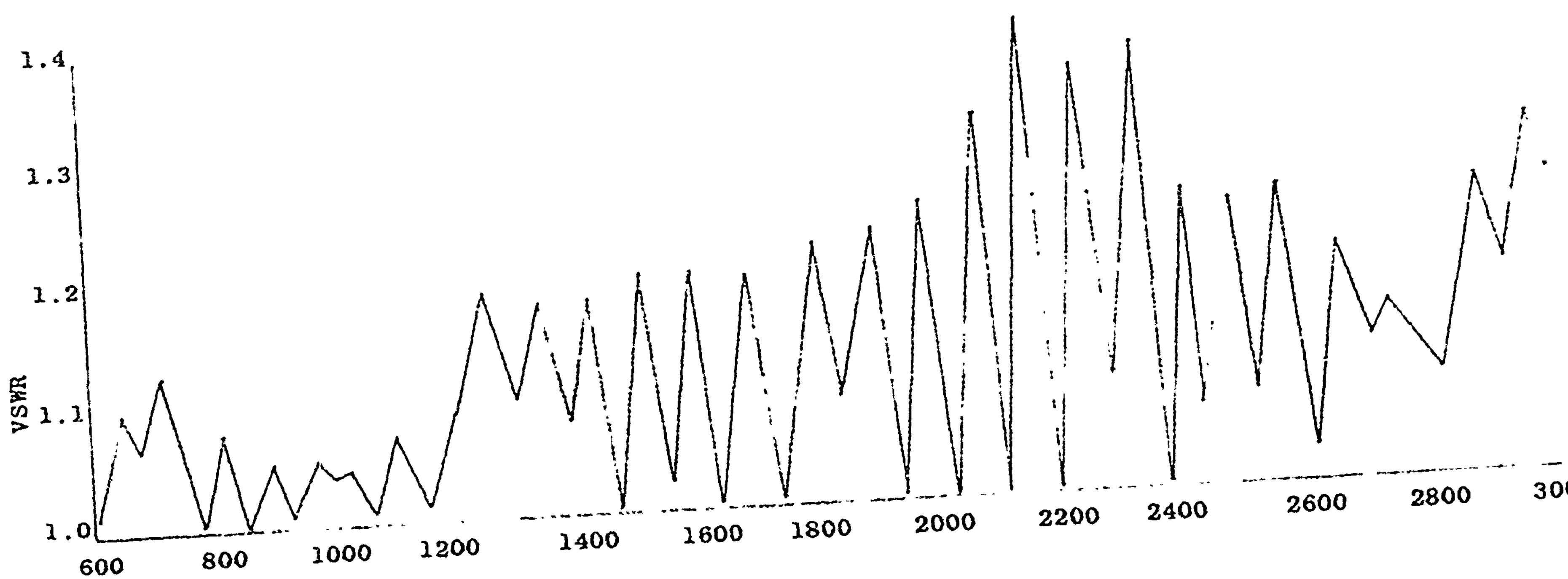


Figure 120.

CABLE "A"

3/8" H. T. HELIAX BENT FOR VIBRATION TESTS
SEE TEST PROCEDURE PAR. 4.5.11

VSWR BEFORE VIBRATION TESTS
(Cable No. 1)

3/8 H. T. HELIAX
3000 to 5000 MC

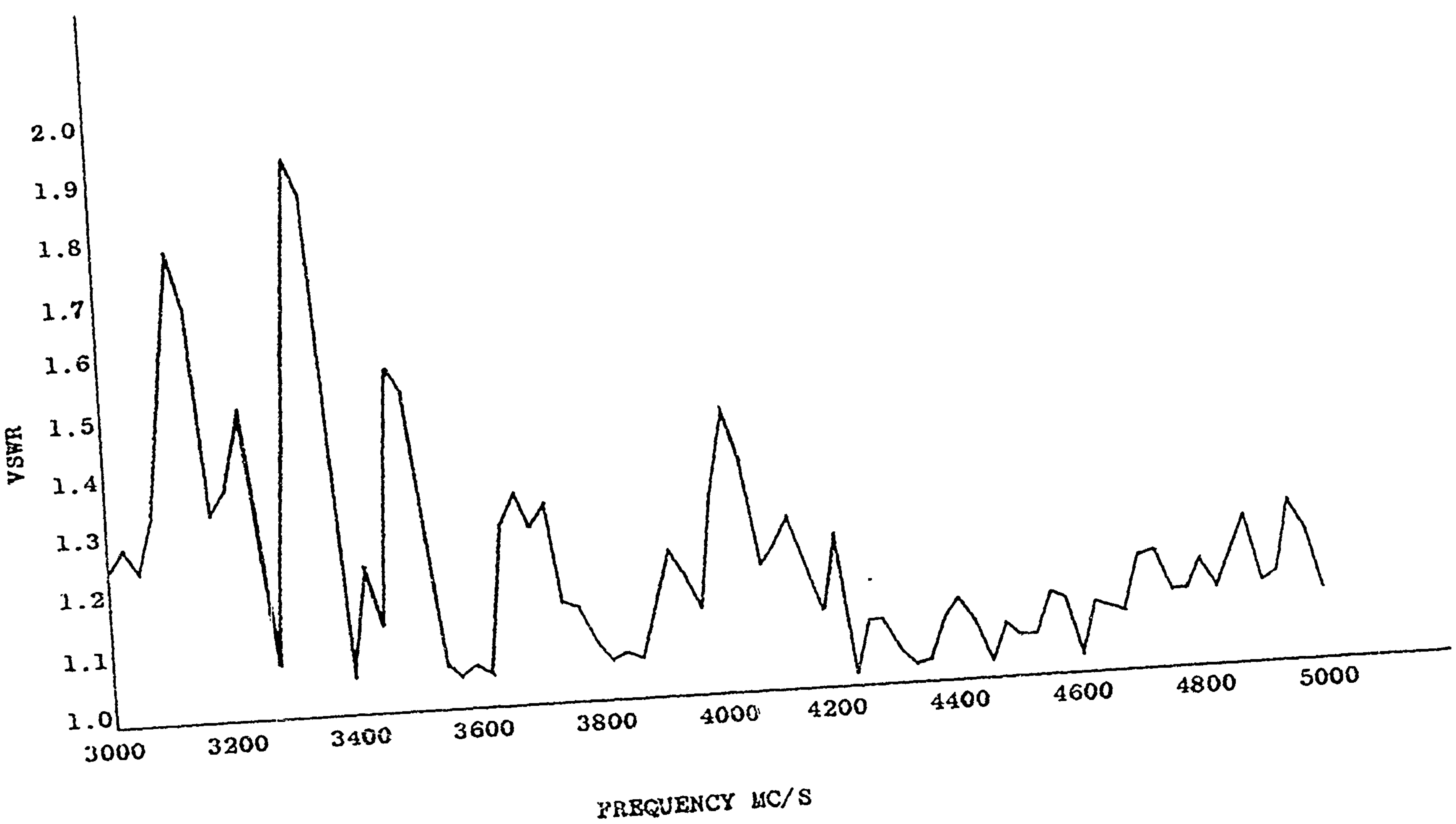


Figure 121.

CABLE "A"

3/8" H.T. HELIAX Bent for Vibration Tests (See Test Procedure Par. 4.5.11)

VSWR Before Vibration Tests
Cable No. 2

S.C. or E.P. No.

Type No

Desc 3/8" H.T. HELIAX

Freq. 600 to 5000 MC

Name

Date

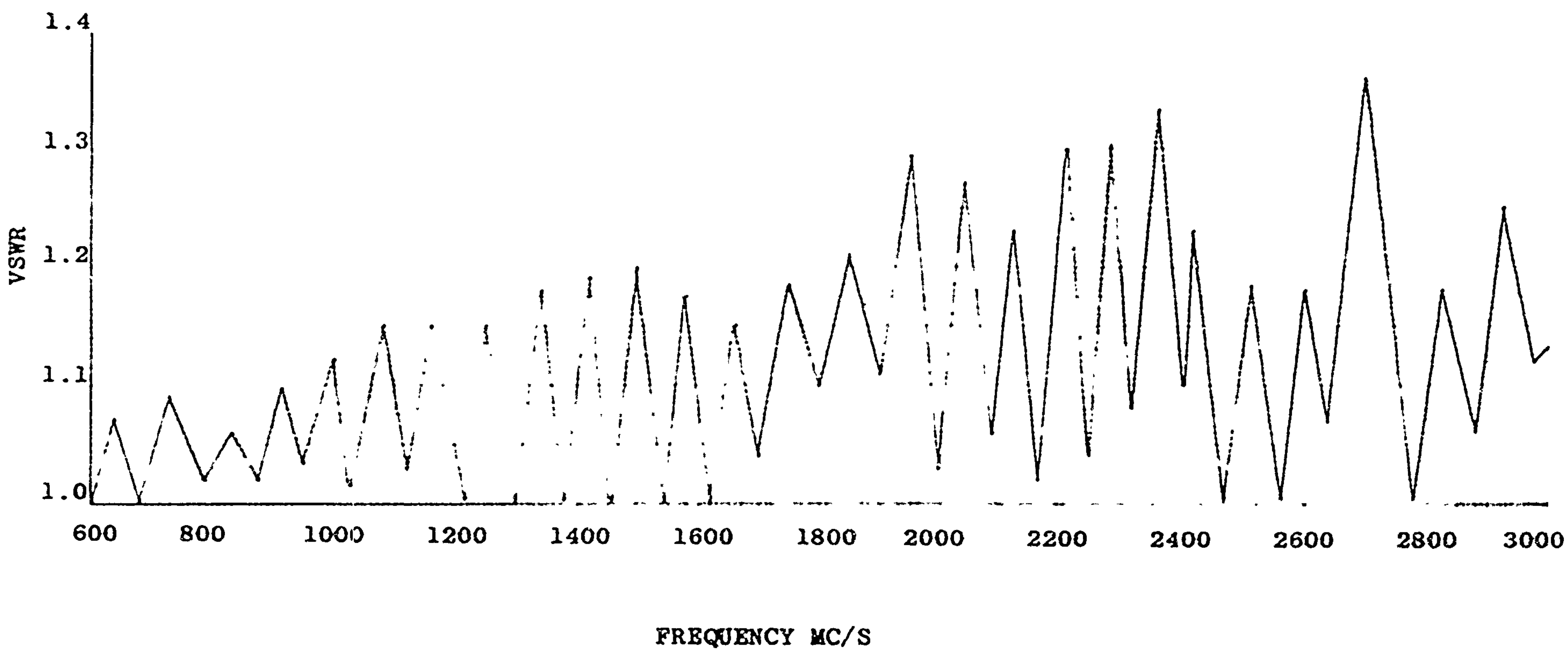
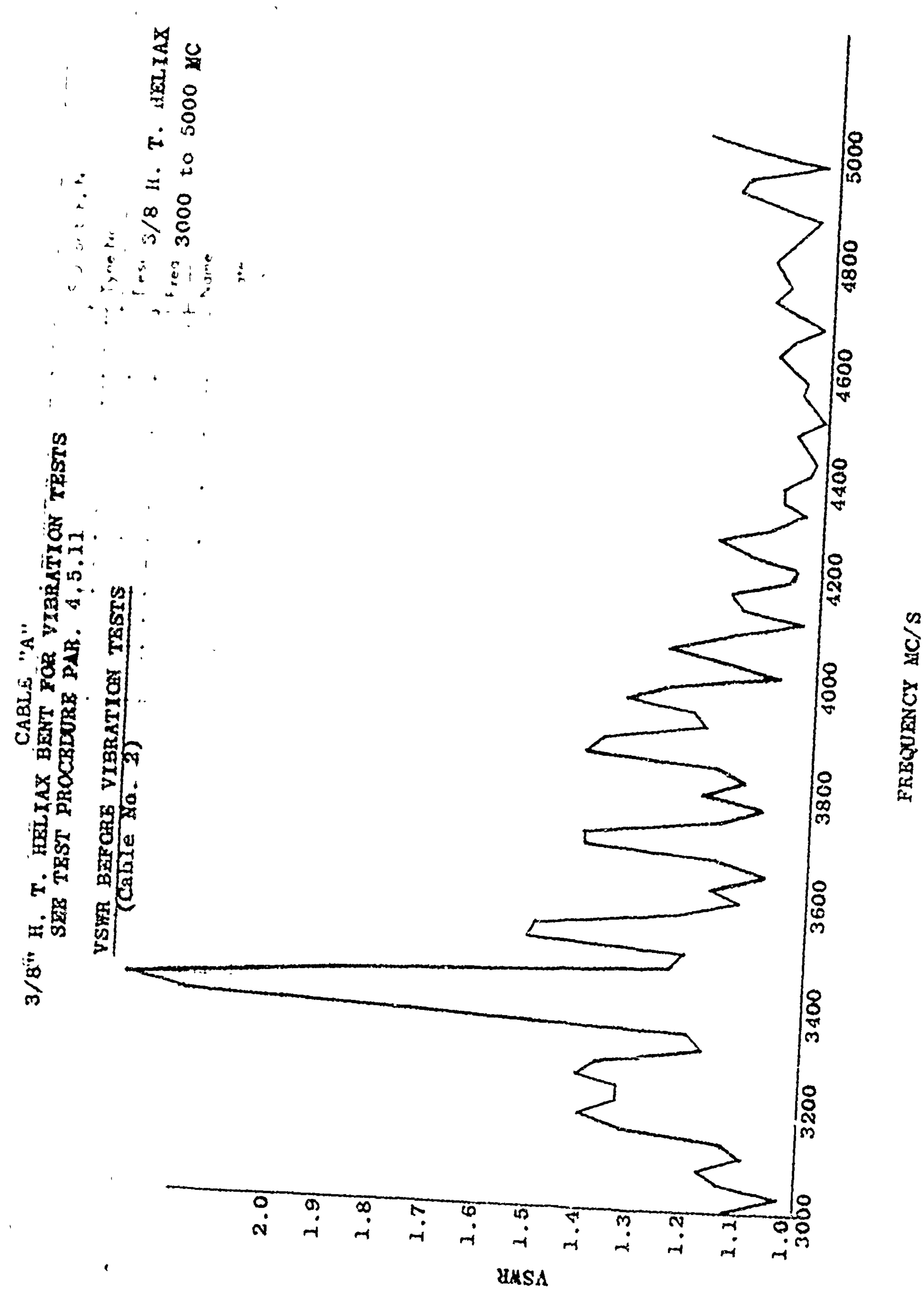


Figure 122.

Figure 123.


CABLE "A"
3/8" H. T. HELIAX BENT FOR VIBRATION TESTS
SEE TEST PROCEDURE PAR. 4.5.11
VSWR BEFORE VIBRATION TESTS
(Cable No. 2)
5/8 H. T. HELIAX
3000 to 5000 MC
VSWR
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
FREQUENCY MC/S

CABLE "A"

VSWR of Prototype Cable No. 1 shipped to ASD

10 Foot length of 3/8" H.T. HELIAX with connectors

S.C. or E.P. No.

Type No.

Desc 3/8" H.T. HELIAX

Freq 600 to 3000

Name

Date

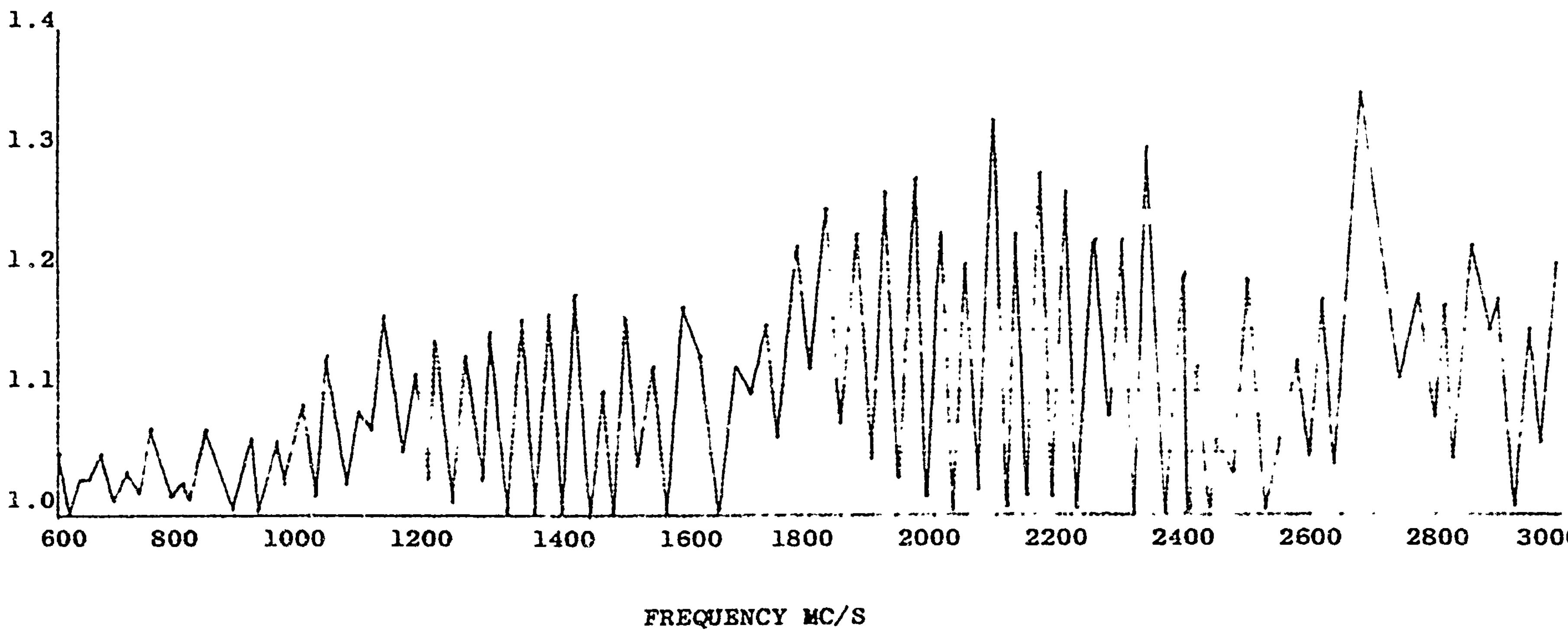


Figure 124.

CABLE "A"

VSWR OF PROTOTYPE CABLE NO. 1 [illegible]PED TO A[illegible]

10 FOOT [illegible] OF 3/8" H. T. HELIAX WITH CO[illegible]

CABLE "A"

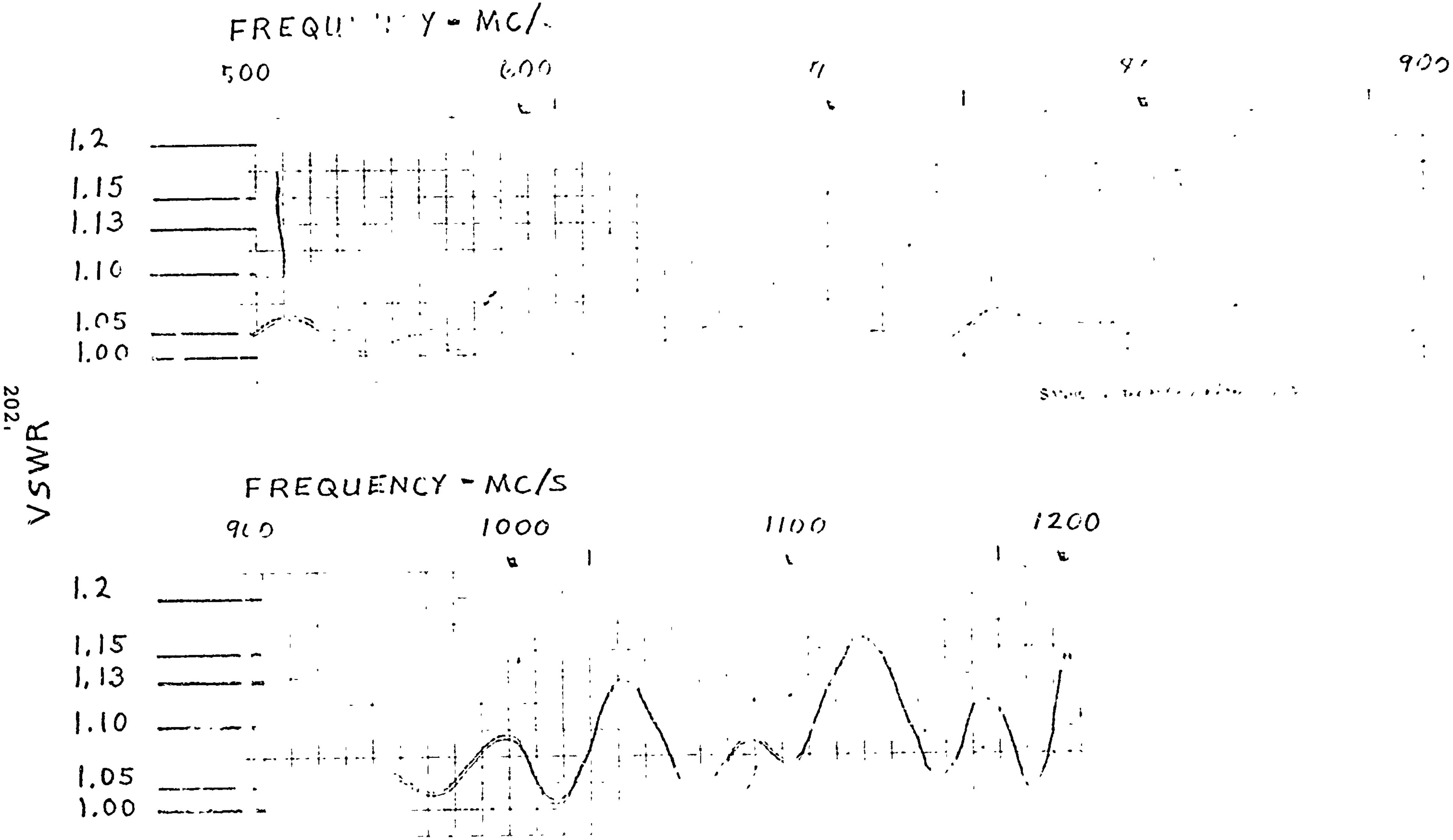


Figure 124 a.

VSWR OF PROTOT... CABLE NO. 1 SHIPPED TO ASD

10 FOOT LENGTH OF 7/8 H. T. HELIAX WITH CONNECTORS
CABLE "A"

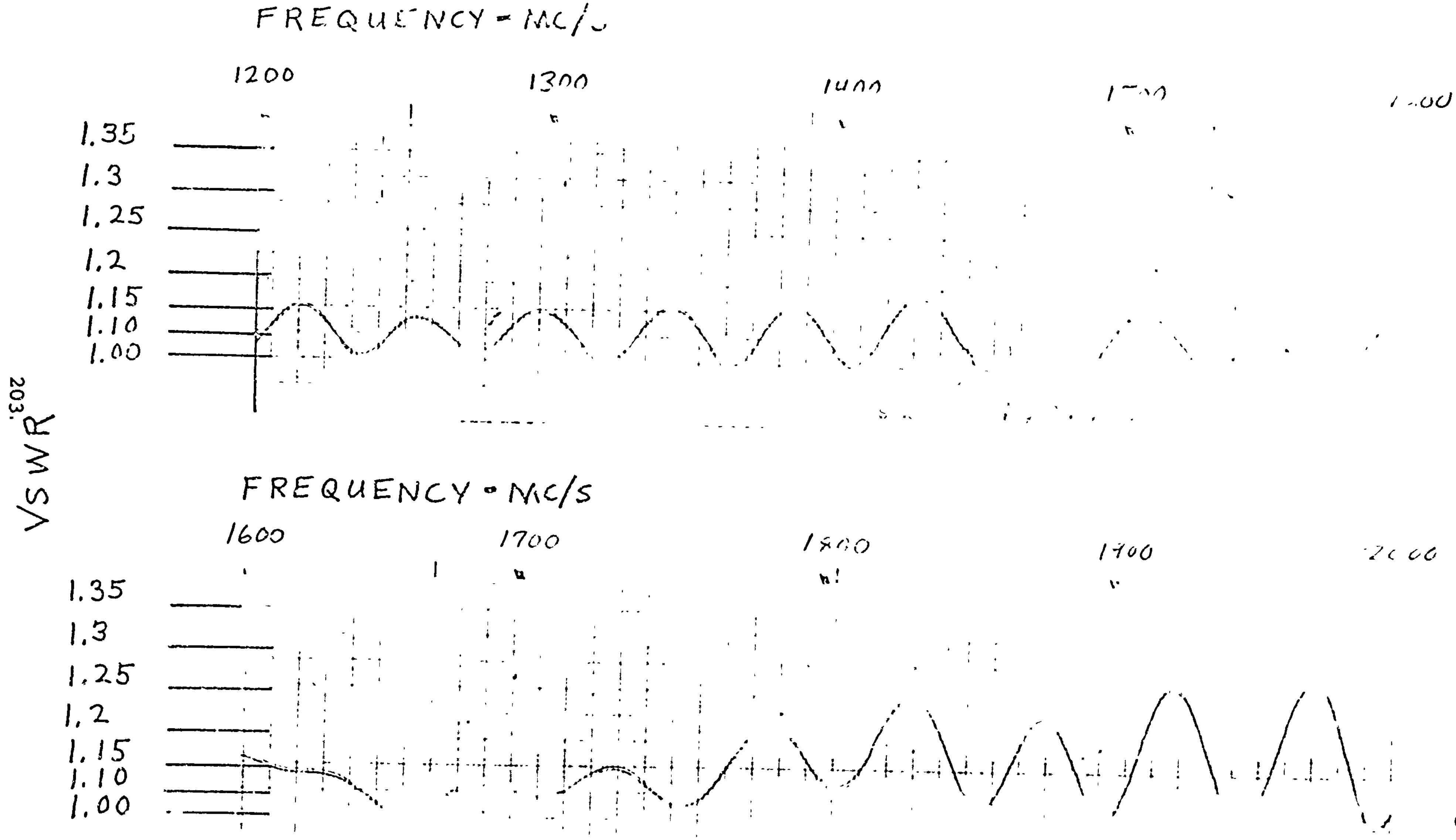


Figure 124 b.

CHART A

VSWR OF PROTOTYPE CABLE NO. 1 SHIPPED TO ASD

10 [illegible] LENGTH [illegible] S/C [illegible] CONNECTORS

CABLE "A"

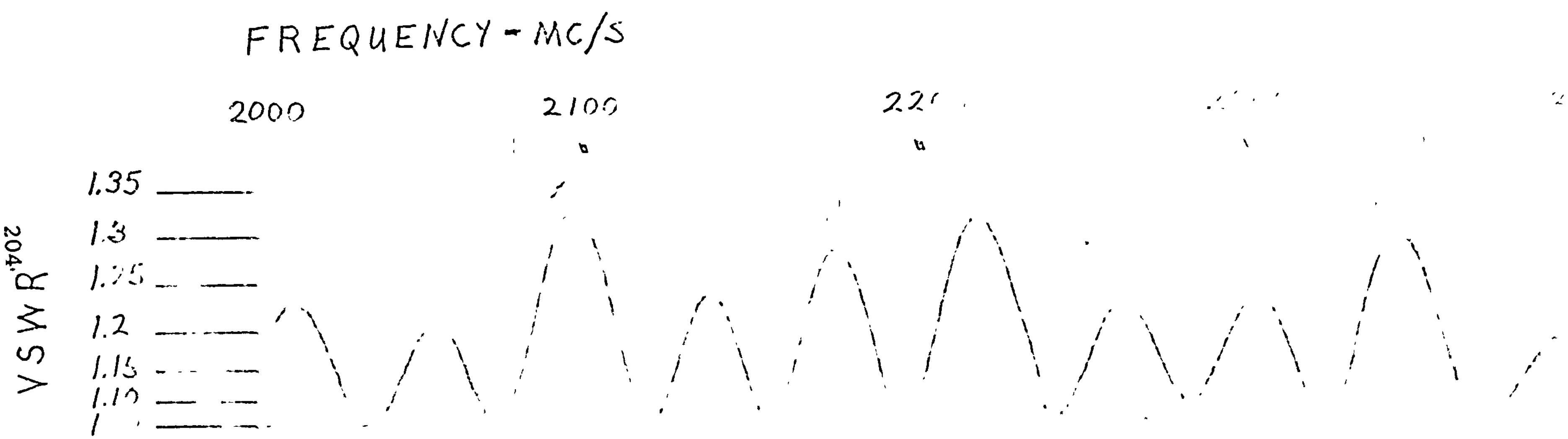


Figure 124 c.

CAJ "A

VSWR OF PROTOTYPE CABLE NO. 1 SHIPPED TO ASD

10 FOOT LENGTH OF [illegible]/8" H. T. HELIAX WITH CONNECTORS
CABLE "A"

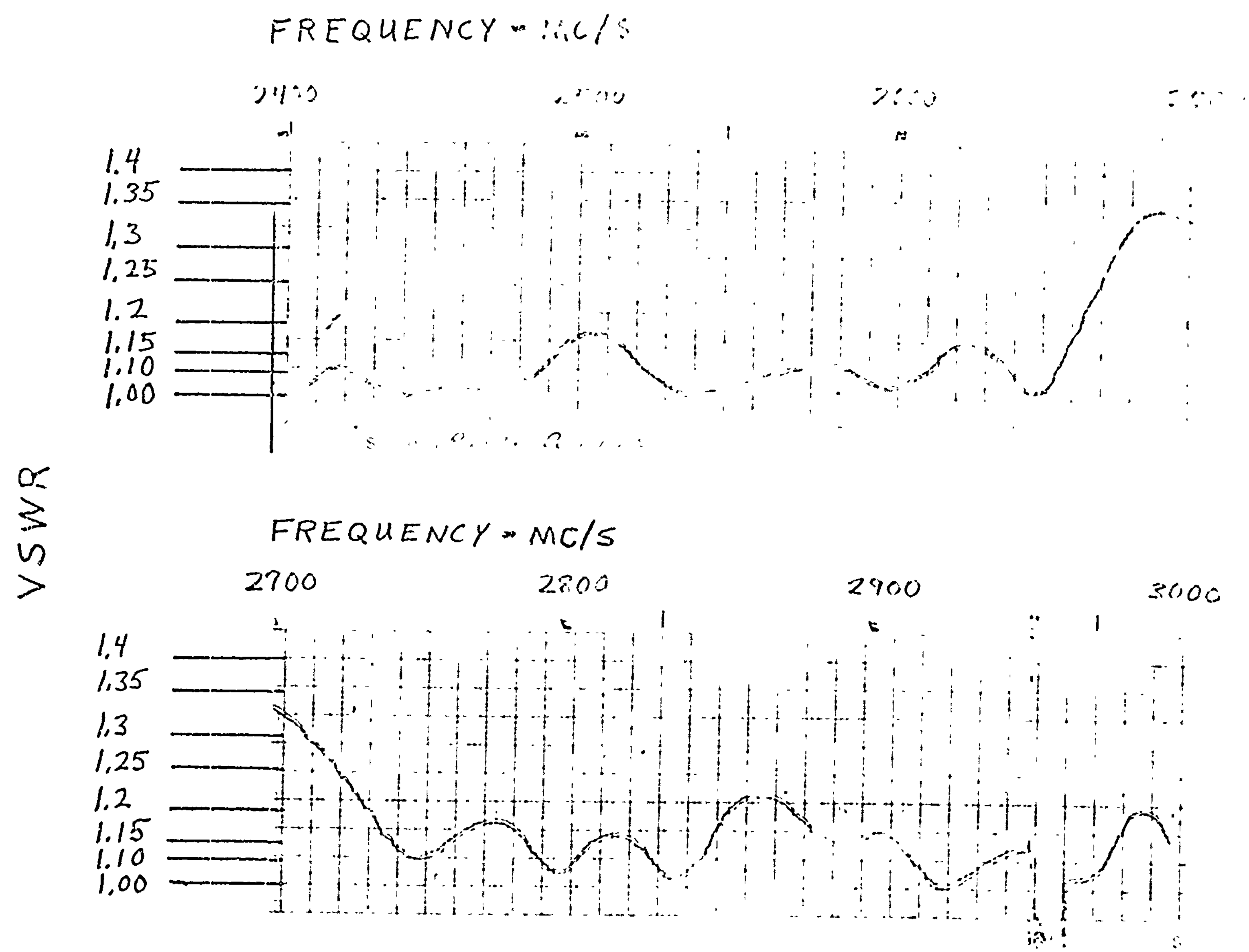
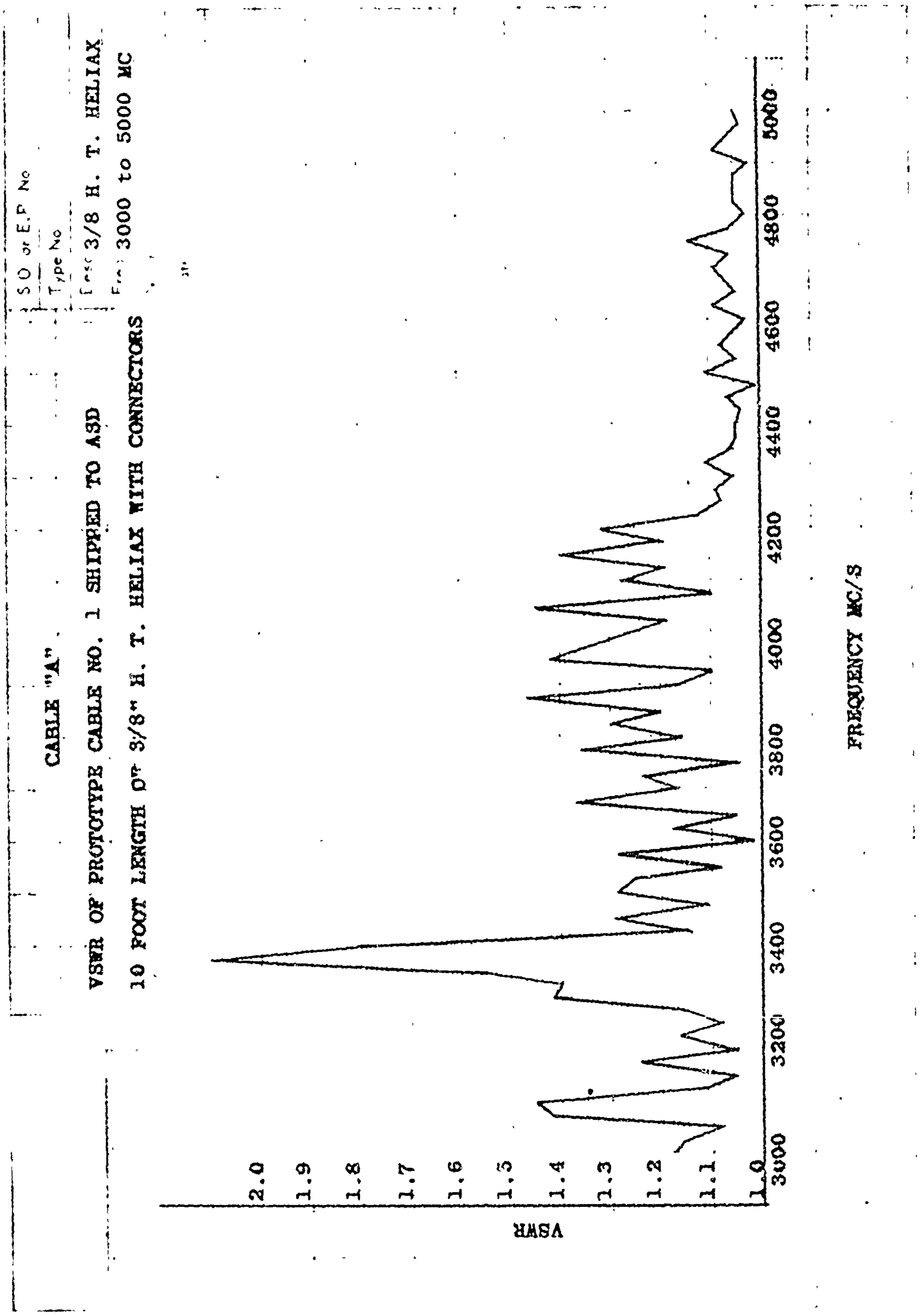


Figure 124 d

Figure 125.


CABLE "A"
VSWR OF PROTOTYPE CABLE NO. 1 SHIPPED TO ASD
10 FOOT LENGTH OF 3/8" H. T. HELIAX WITH CONNECTORS
Type No
3/8 H. T. HELIAX
3000 to 5000 MC
VSWR
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
FREQUENCY MC/S

CABLE "A"

VSWR of Prototype Cable No. 2 shipped to ASD

10 Foot length of 3/8" H.T. HELIAX with connectors

Desc 3/8" H.T. HELIAX

Freq 600 to 3000 MC

Name

Date

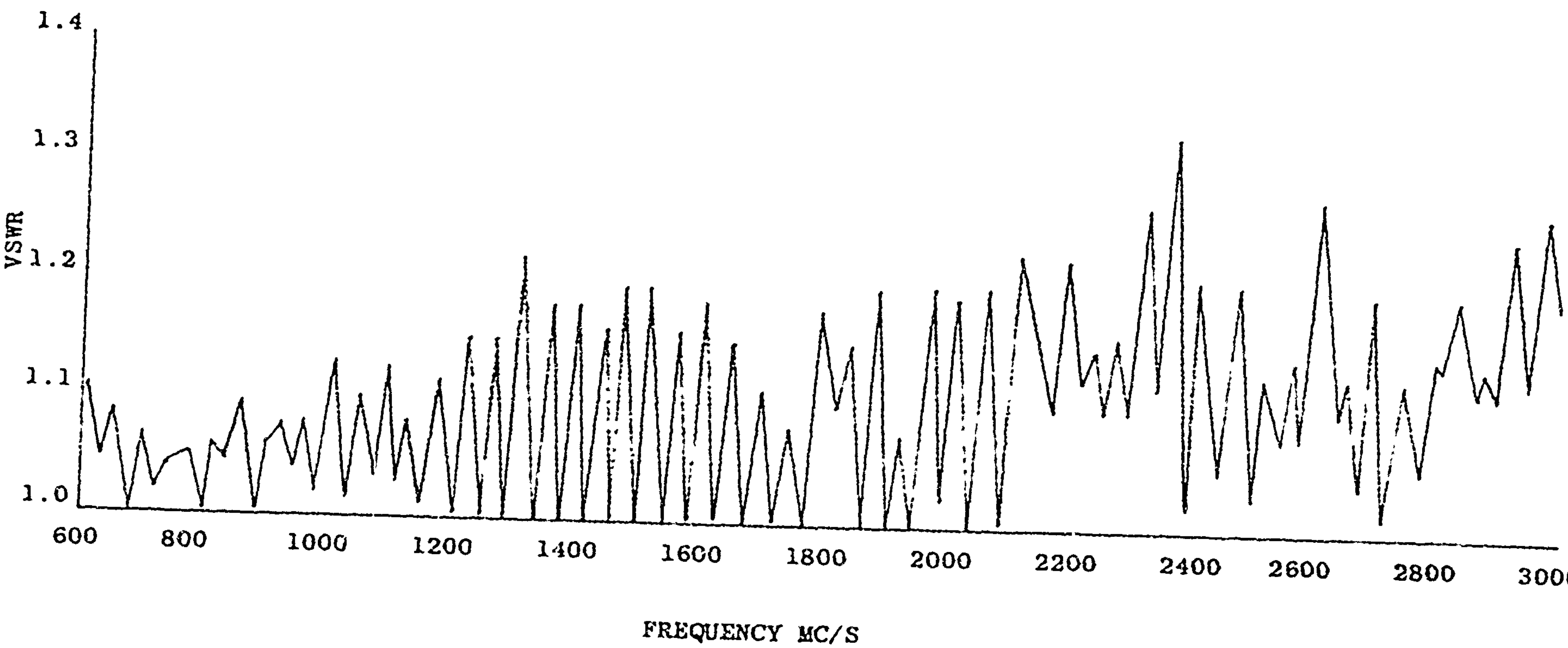


Figure 126.

Figure 127.

CABLE "A"

VSWR OF PROTOTYPE CABLE NO. 2 SHIPPED TO ASD

10 FOOT LENGTH OF 3/8" H. T. HELIAX WITH CONNECTORS

3/8 H. T. HELIAX

3000 to 5000 MC

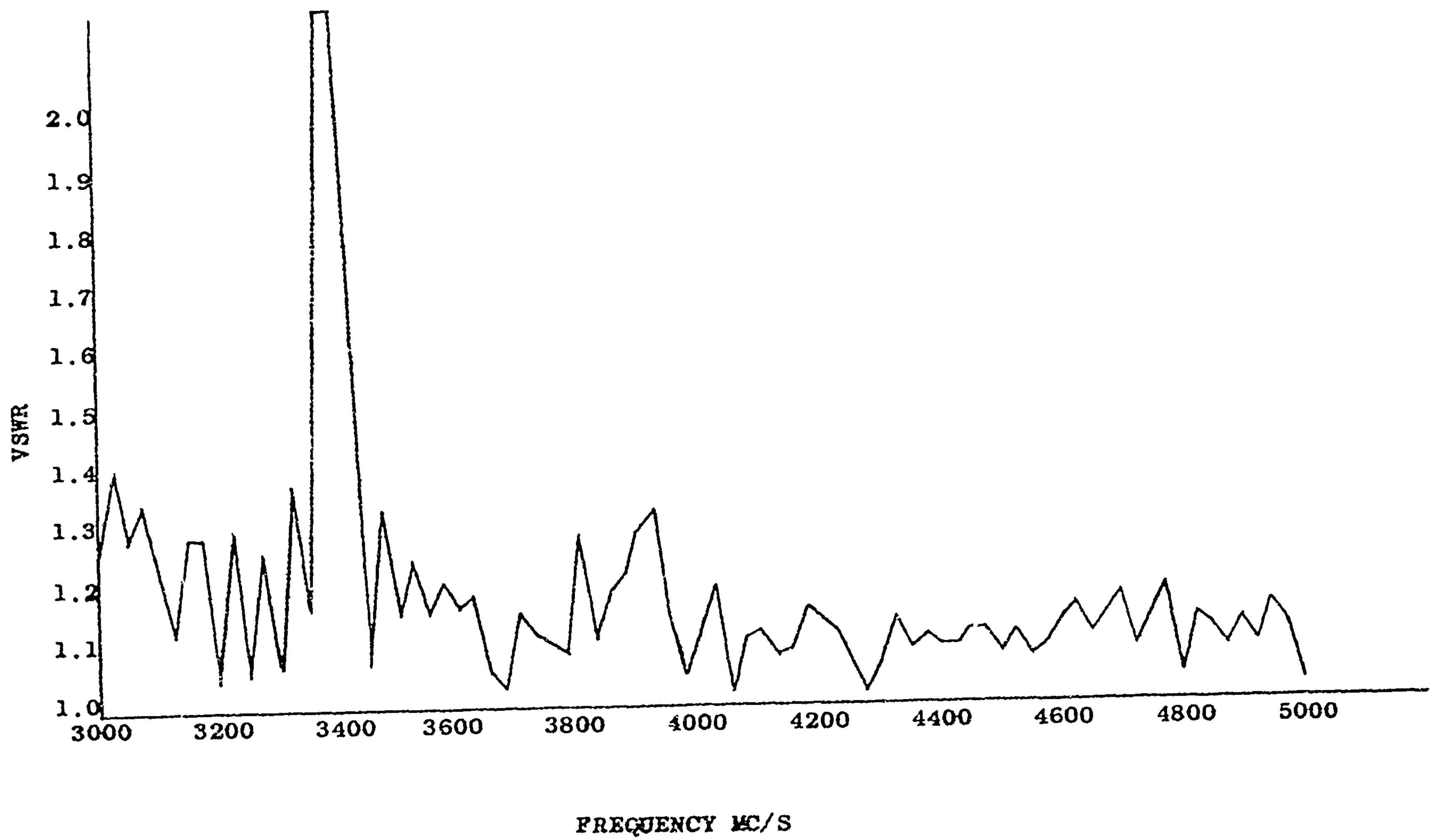
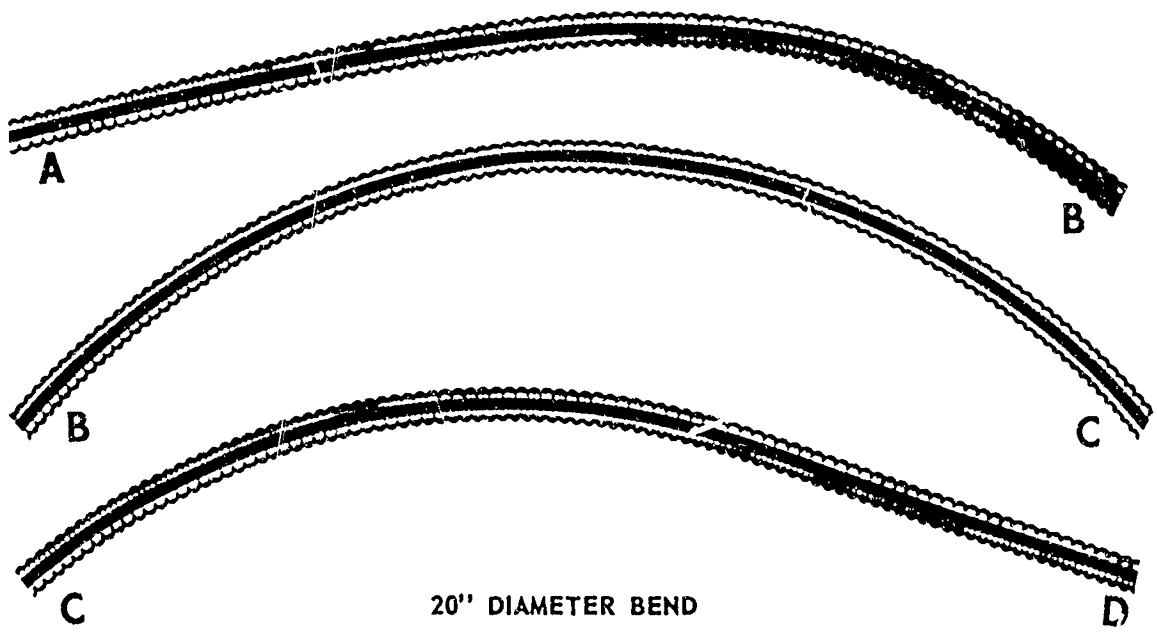


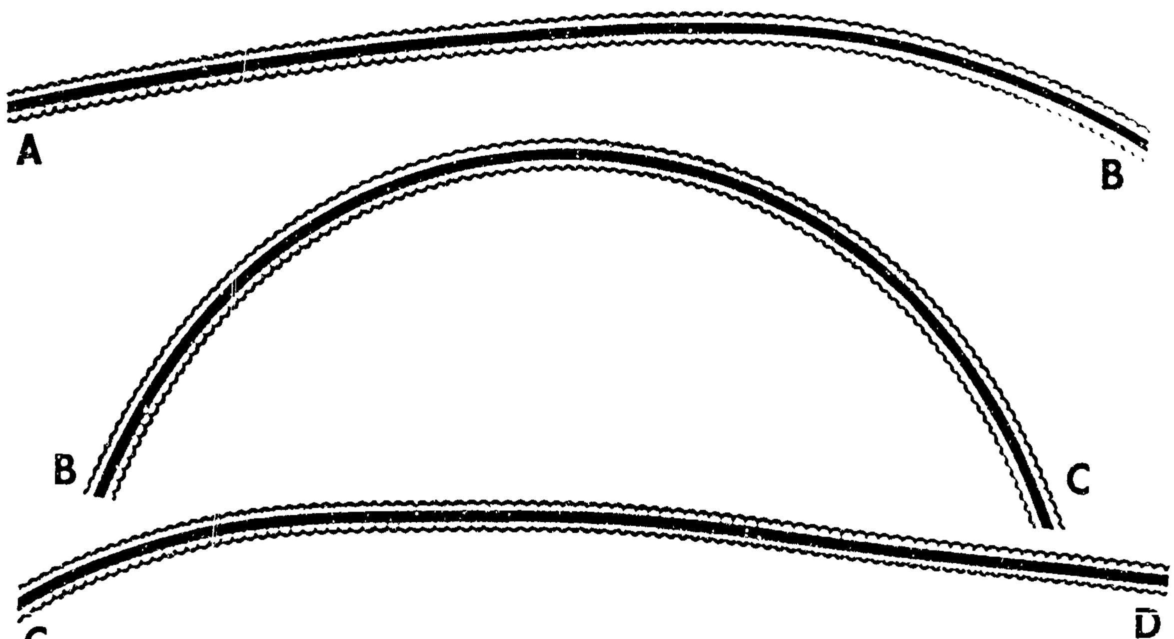
Figure 128.

CABLE "A"

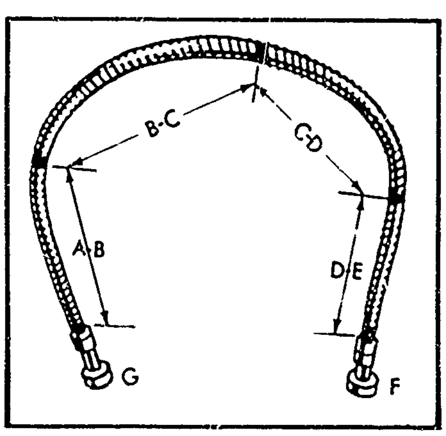
VSWR AND BEND RADIUS TESTS



20" DIAMETER BEND



15" DIAMETER BEND

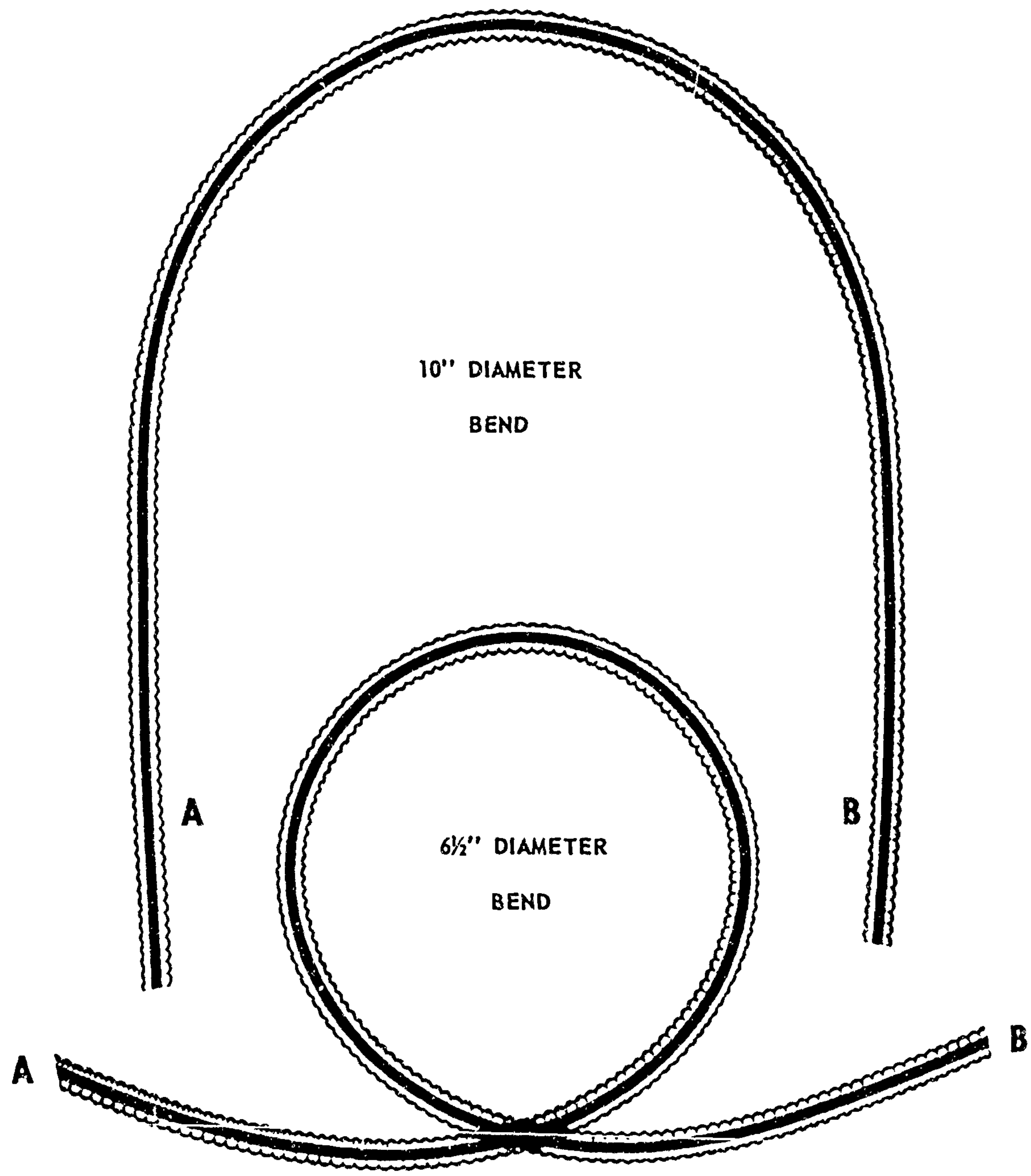


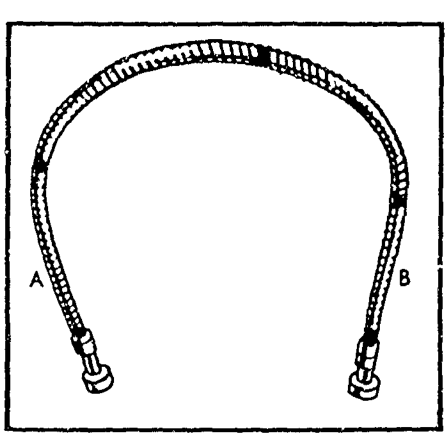
TEST CABLE
TYPE 26459
3/8" HIGH TEMPERATURE
HELIAX

Figure 129.

CABLE "A"

VSWR AND BEND RADIUS TESTS





TEST CABLE

TYPE 26459

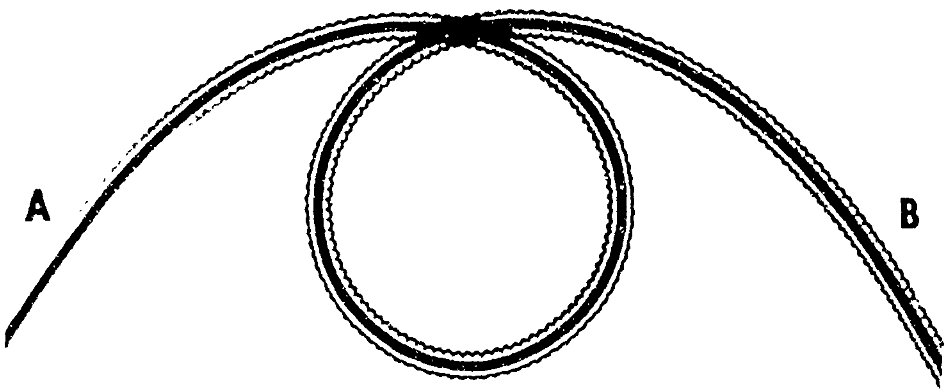
3/8" HIGH TEMPERATURE

HELIAX

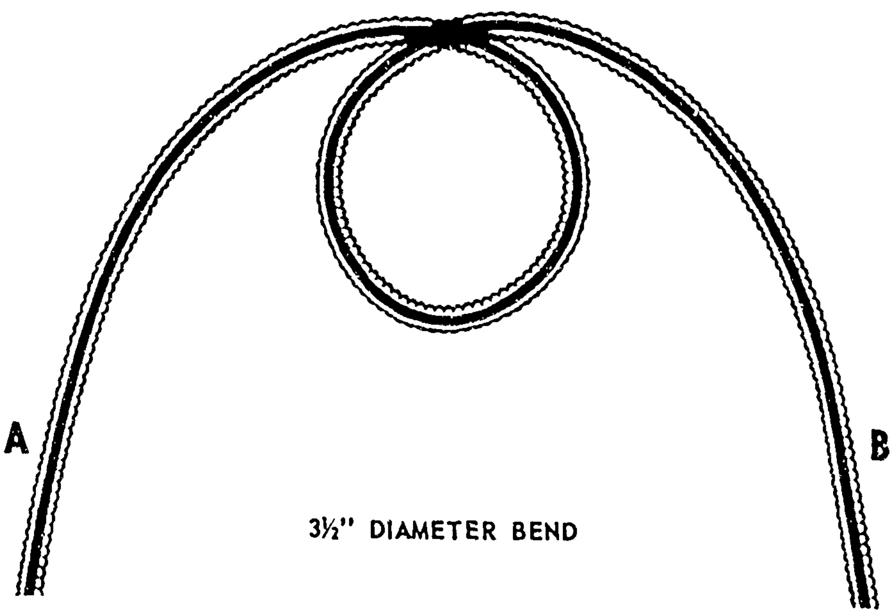
Figure 130.

CABLE "A"

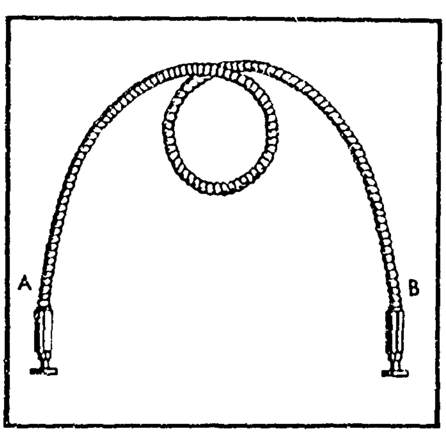
VSWR AND BEND RADIUS TESTS



4½" DIAMETER BEND



3½" DIAMETER BEND



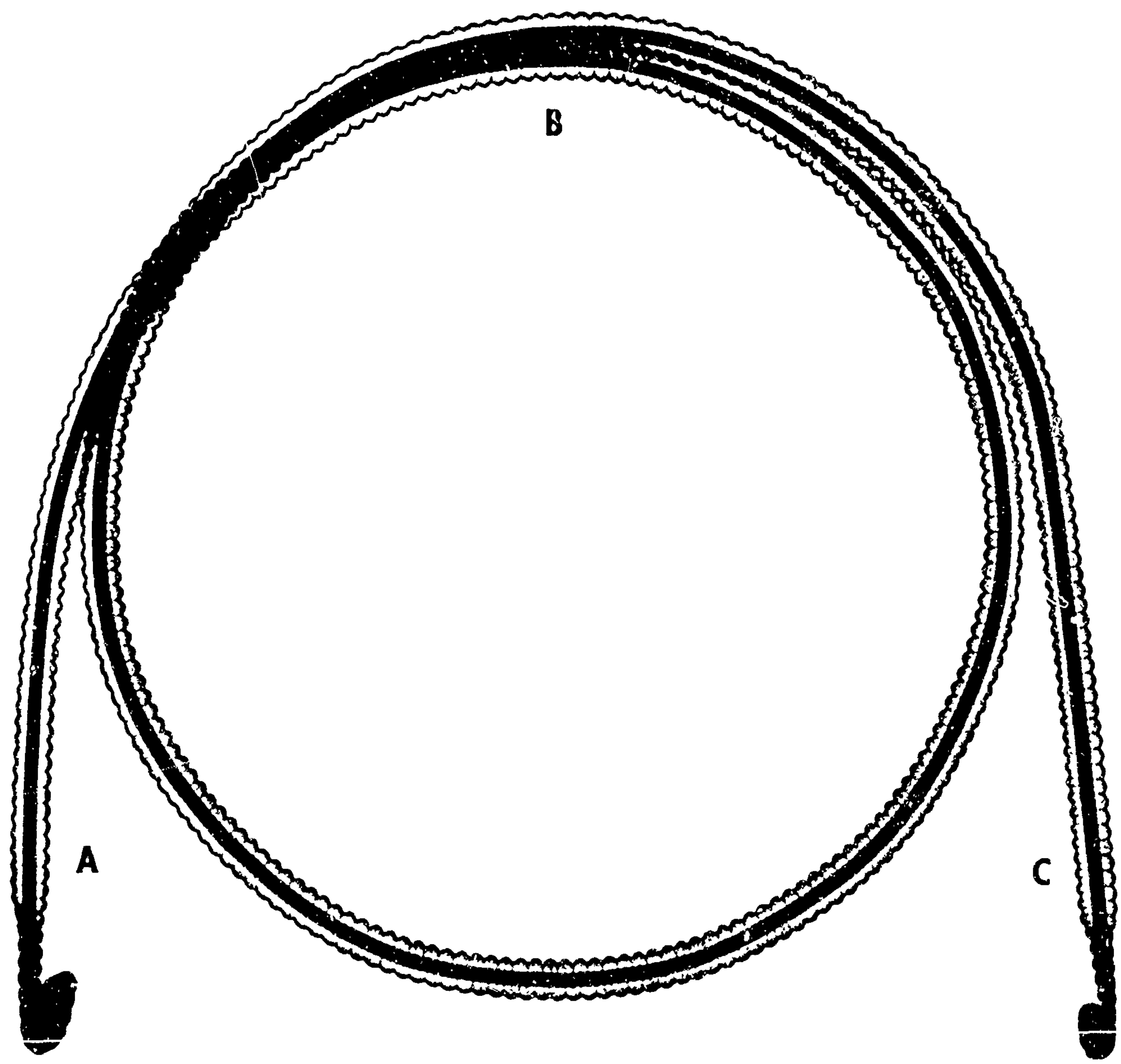
TEST CABLE
TYPE 26459 3/8" HIGH TEMPERATURE **HELIAX**

Figure 131.

CABLE "A"

AFTER 10 CYCLES OF THERMAL SHOCK

-65° C TO 825°C



EXPERIMENTAL CABLE

3/8" HIGH TEMPERATURE

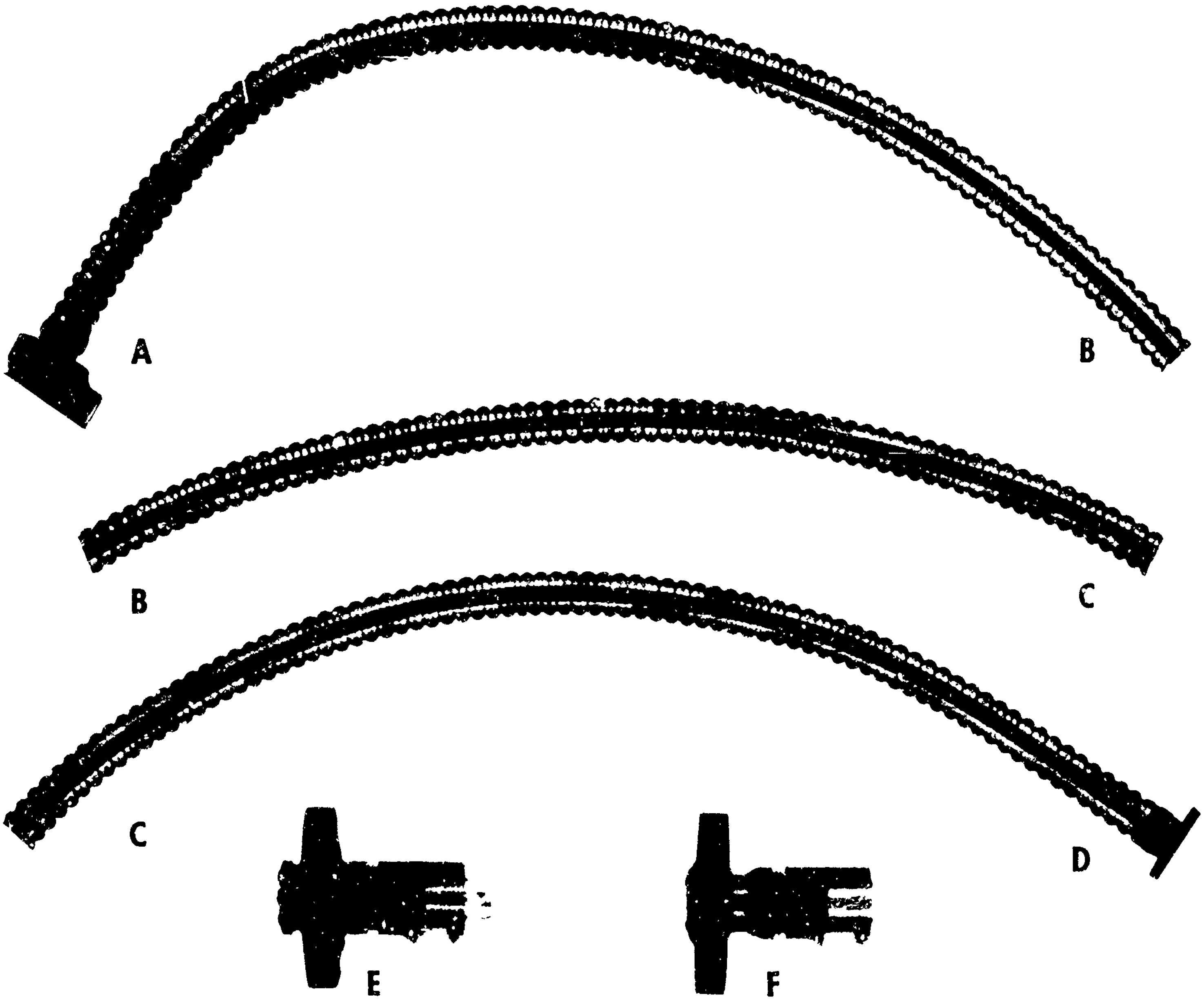
HELIAX

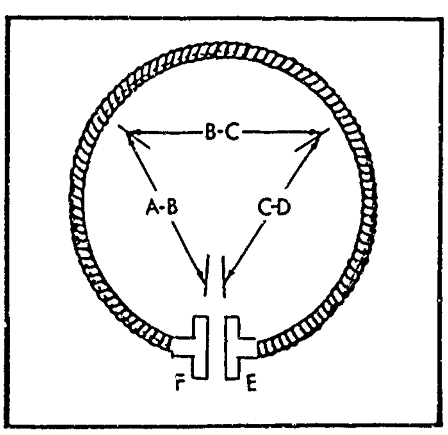
Figure 132.

CABLE "A"

AFTER 5 CYCLES OF THERMAL SHOCK

(~~XXXXC~~ To 825° C)
-65°C





TEST CABLE

TYPE 26459

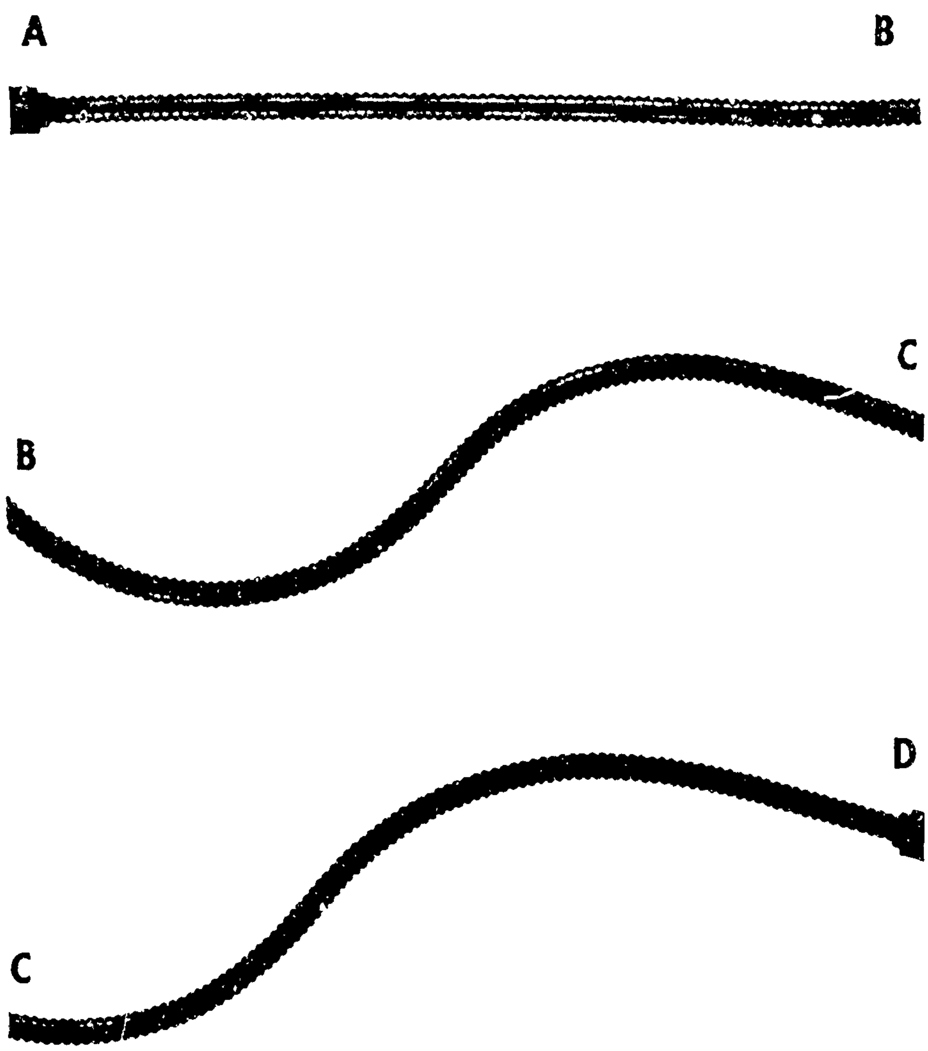
3/8" HIGH TEMPERATURE

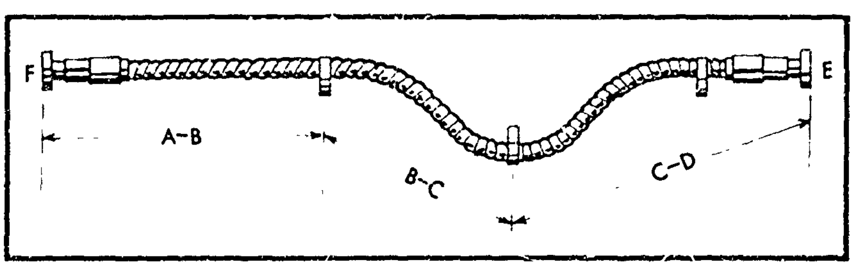
HELIAX

Figure 133.

CABLE "A"

AFTER VIBRATION TEST





TEST CABLE

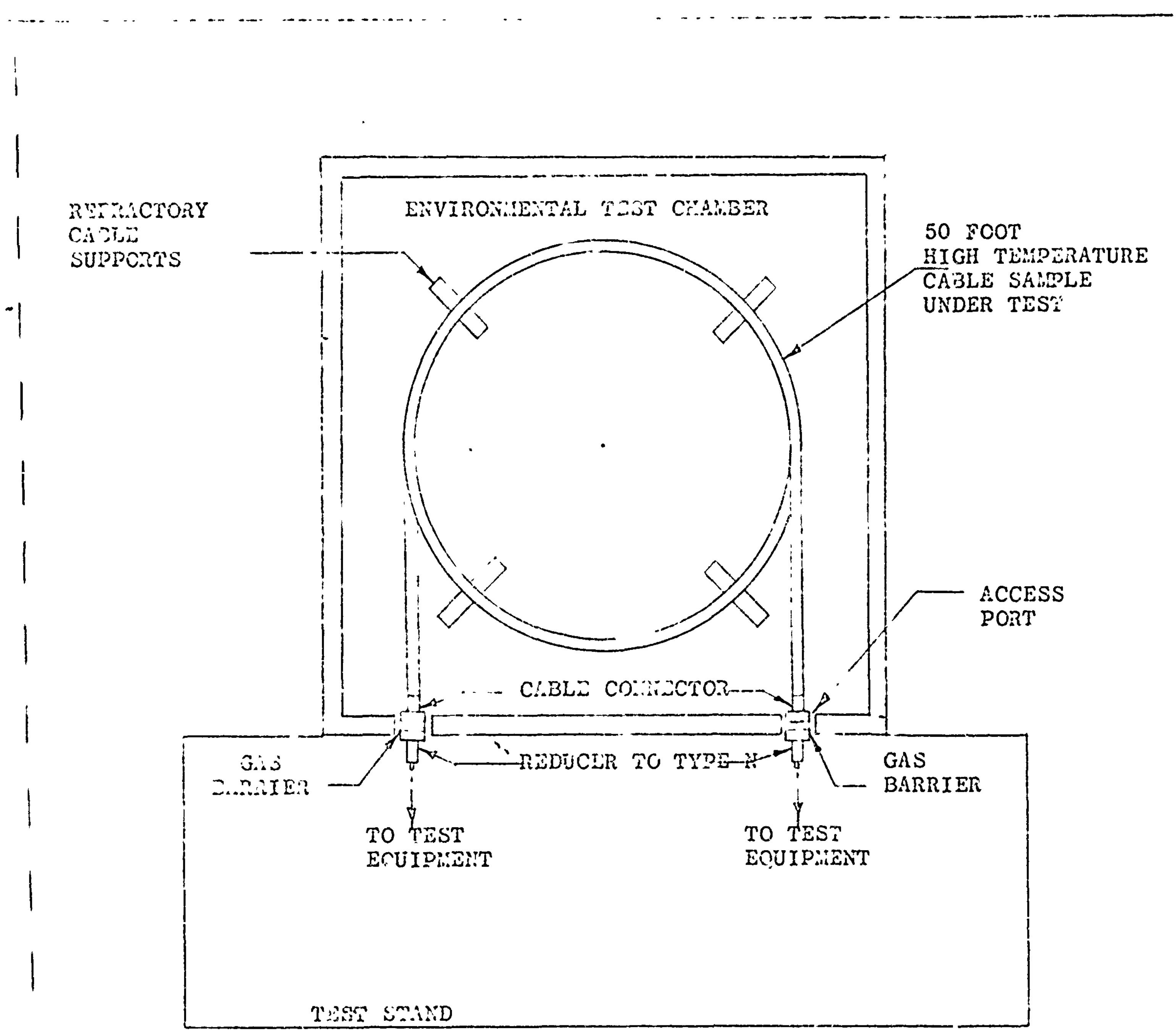
TYPE 26459

3/8" HIGH TEMPERATURE

HELIAX

HIGH TEMPERATURE CABLE TESTING

CABLES "A" & "B"

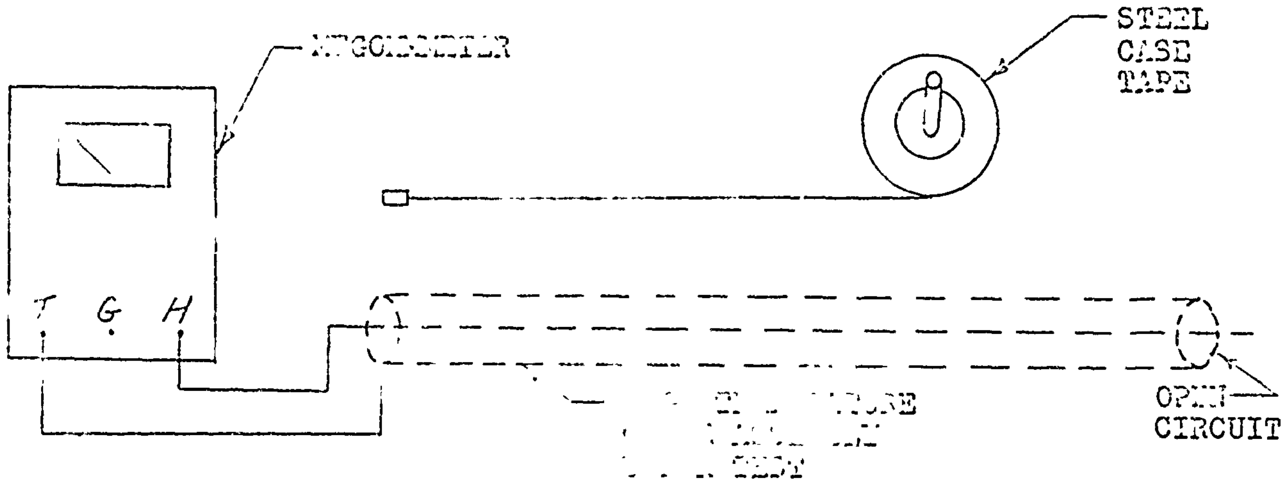


TOP VIEW

FIGURE 134

REFERENCE
MIL-C-17D Para. 4.[illegible].5
J-C-93 Method 6031

INSULATION RESISTANCE TESTS



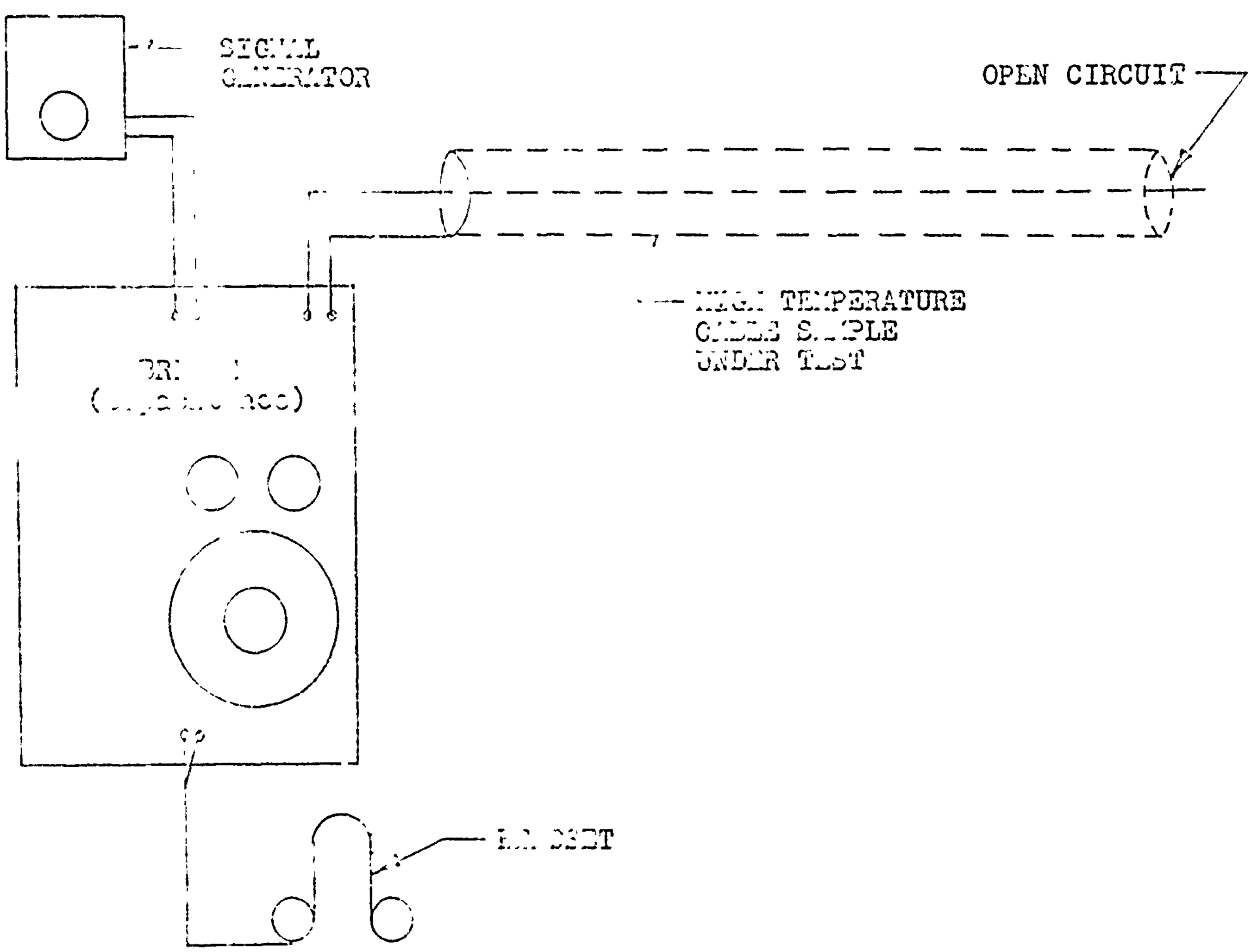
TEST EQUIPMENT CATEGORY	TYPE	NO. REQ'D
Megohmmeter	Industrial Instruments L-7	1
Steel Case Tape	Starrett No. 520 (100 ft)	1

FIGURE 135

REFERENCE

MIL-C-17D para. 4.6.8

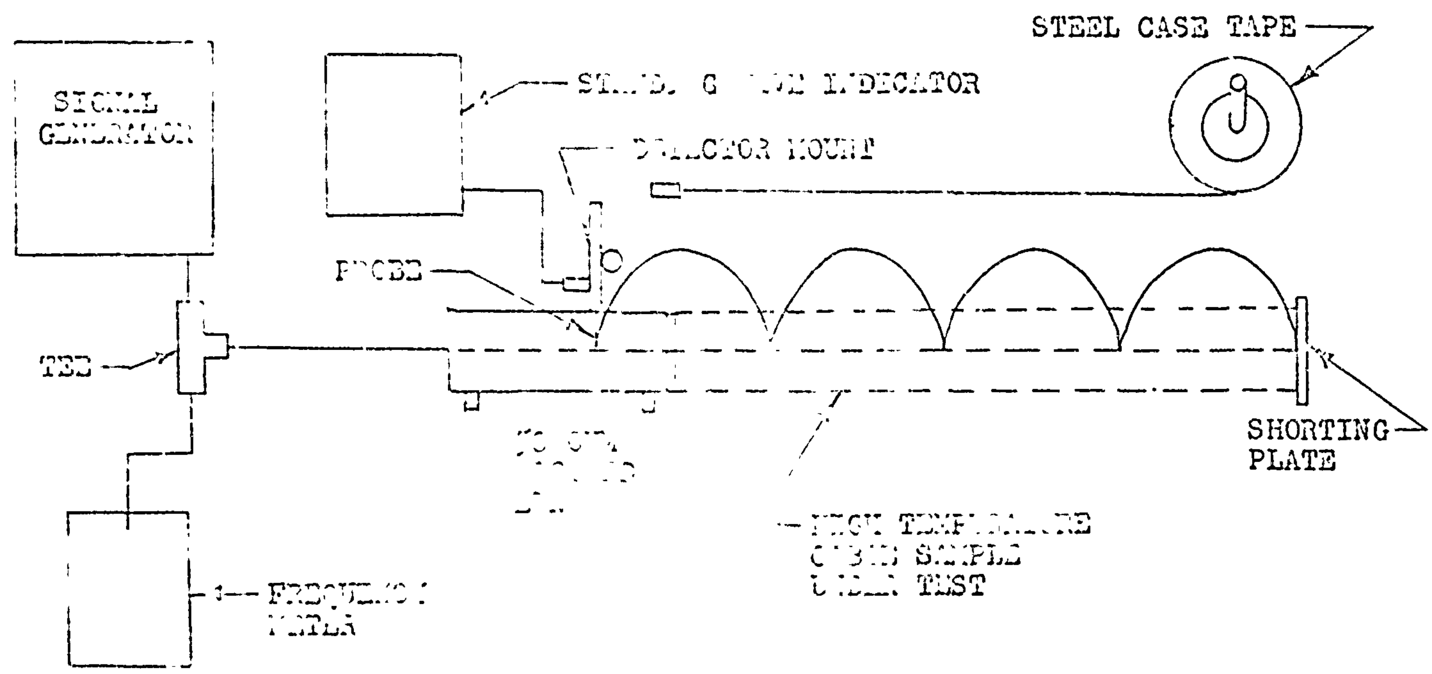
CAPACITANCE STABILITY



TEST EQUIP. CATEGORY	TYPE	NO. REQ'D
Bridge (capacitance)	General Radio [illegible]	1
1 MC Signal Generator	General Radio [illegible]	1
Electric Furnace	[illegible] 231 SP	1
Low Temperature Chamber	Webber [illegible]-50-175-1000	1

FIGURE 136

VELOCITY [illegible]



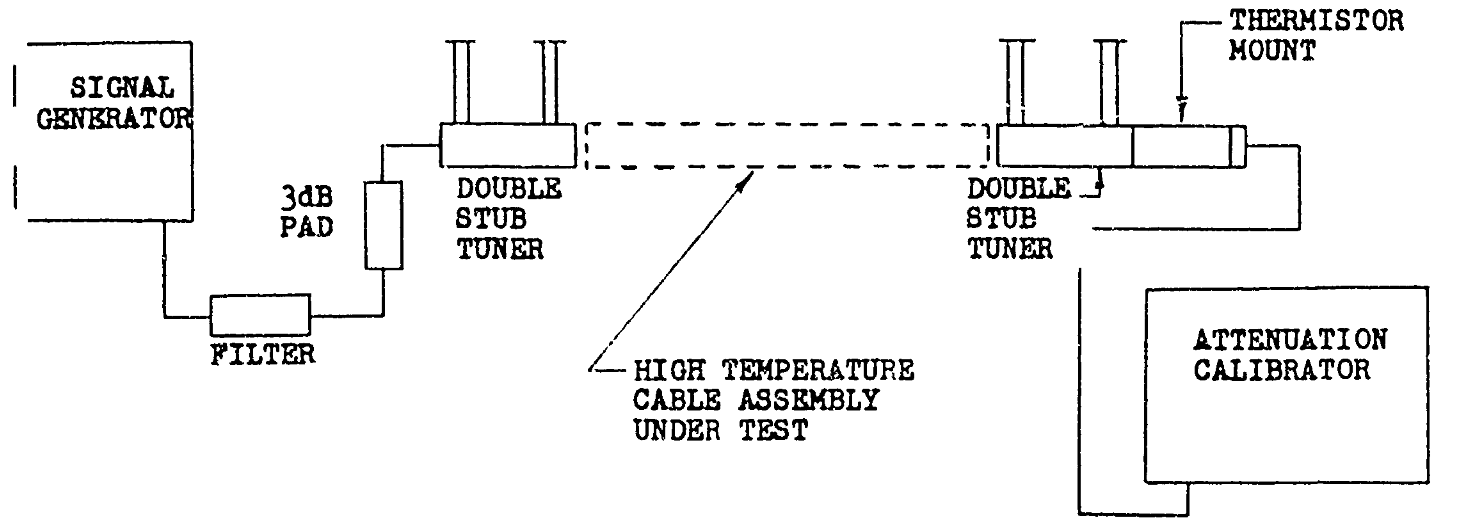
TEST EQUIPMENT CATEGORY	[illegible]	NO. REQ'D
Signal Generator	[illegible] Packard 608C	1
Standing Wave Indicator	[illegible] Packard 415B	1
Frequency Meter	[illegible] FM 3	1
Detector Mount	[illegible] 440A	1
Slotted Line	[illegible] 3/8" 50 ohm [illegible] 7/8" 50 ohm	1 1
Shorting Plate	[illegible] Co. 3/8" [illegible] Co. 7/8"	1 1
[illegible]	[illegible] 82-102 type N	1
[illegible] Tape	[illegible] 100 ft	1

FIGURE 137

REFERENCE

MIL-C-17D para. 4.6.10

ATTENUATION MEASUREMENTS



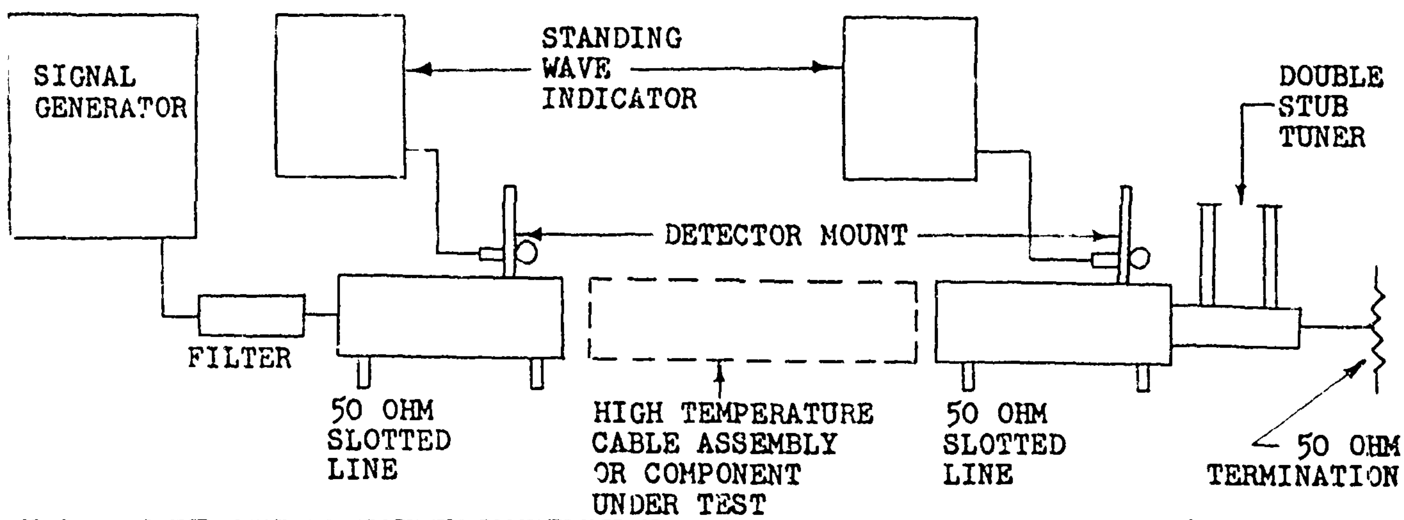
TEST EQUIPMENT CATEGORY	TYPE	NO. REQ'D
Signal Generator	Hewlett Packard 618B Hewlett Packard HO 4616A Hewlett Packard 614A Hewlett Packard 612A Hewlett Packard 608C	1 1 1 1 1
Attenuation Calibrator	Weinschel BA-5	1
Thermistor Mount	Hewlett Packard 477B	1
Double Stub Tuner	Narda 903 Microlab SD 300	1 1
Filter	Microlab FL-5001 Microlab FL-3001 Microlab FL-1001	1 1 1
Attenuator Pad	Microlab AF-3	1

FIGURE 138

NO MIL. REFERENCE

LABORATORY TEST PROCEDURE AND EQUIPMENT SETUP

VSWR MEASUREMENTS



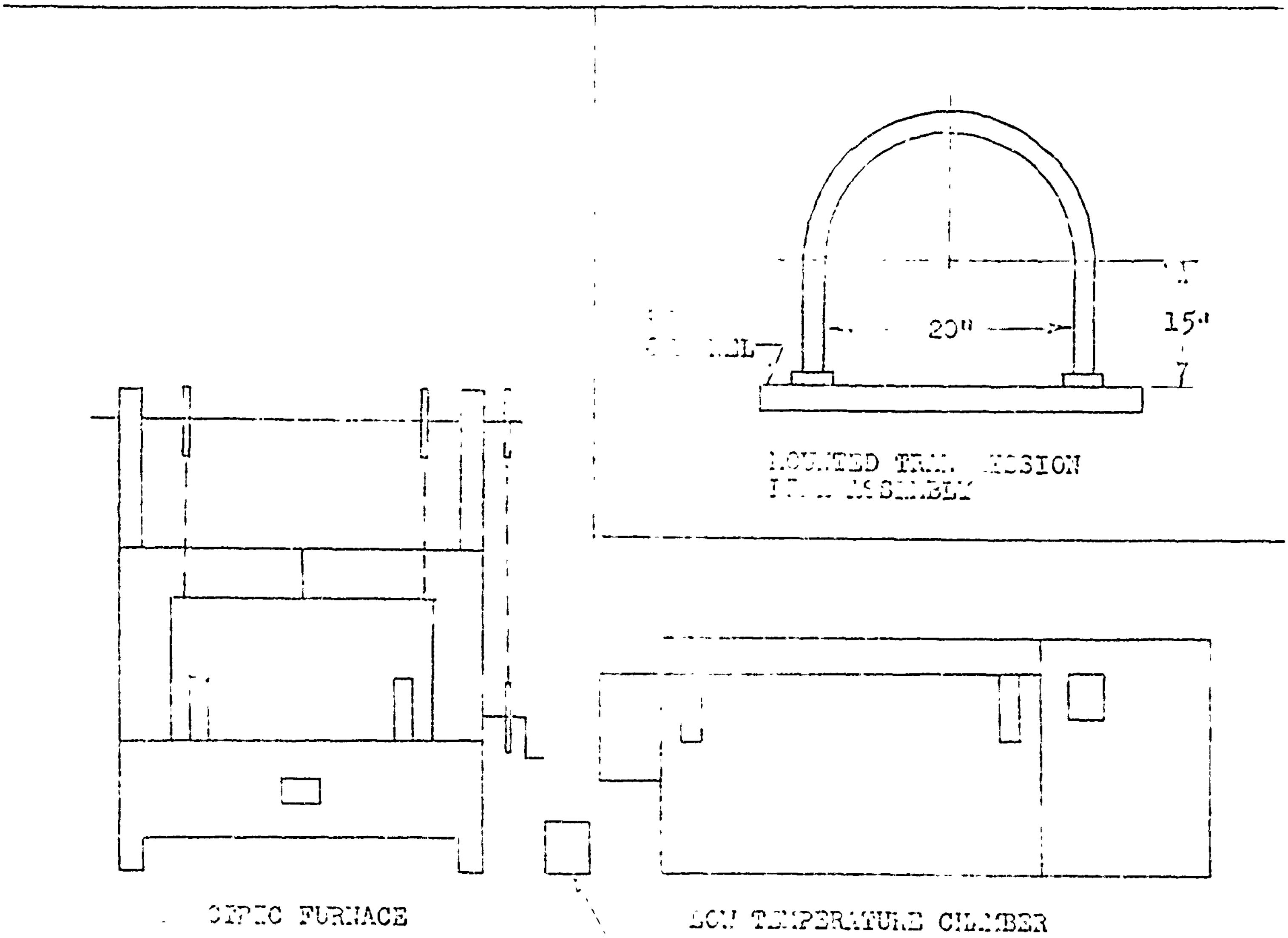
TEST EQUIPMENT CATEGORY	TYPE	NO. REQ'D
Signal Generator	Hewlett Packard 618B Hewlett Packard HO 4616A Hewlett Packard 614A Hewlett Packard 612A Hewlett Packard 608C	1 1 1 1 1
Standing Wave Indicator	Hewlett Packard 415B	2
Slotted Line	Andrew Co. 3/8" 50 ohm Andrew Co. 7/8" 50 ohm	2 2
Double Stub Tuner	Narda 903 Microlab SD300	1
Filter	Microlab FL-5001 Microlab FL-3001 Microlab FL-1001	1 1 1
Detector Mount	Hewlett Packard 440A	2
50 Ohm Termination	Bird 80M	1

FIGURE 139

[illegible]
[illegible] 5272 (general)

TEST SETUP

THERMAL SHOCK TESTS

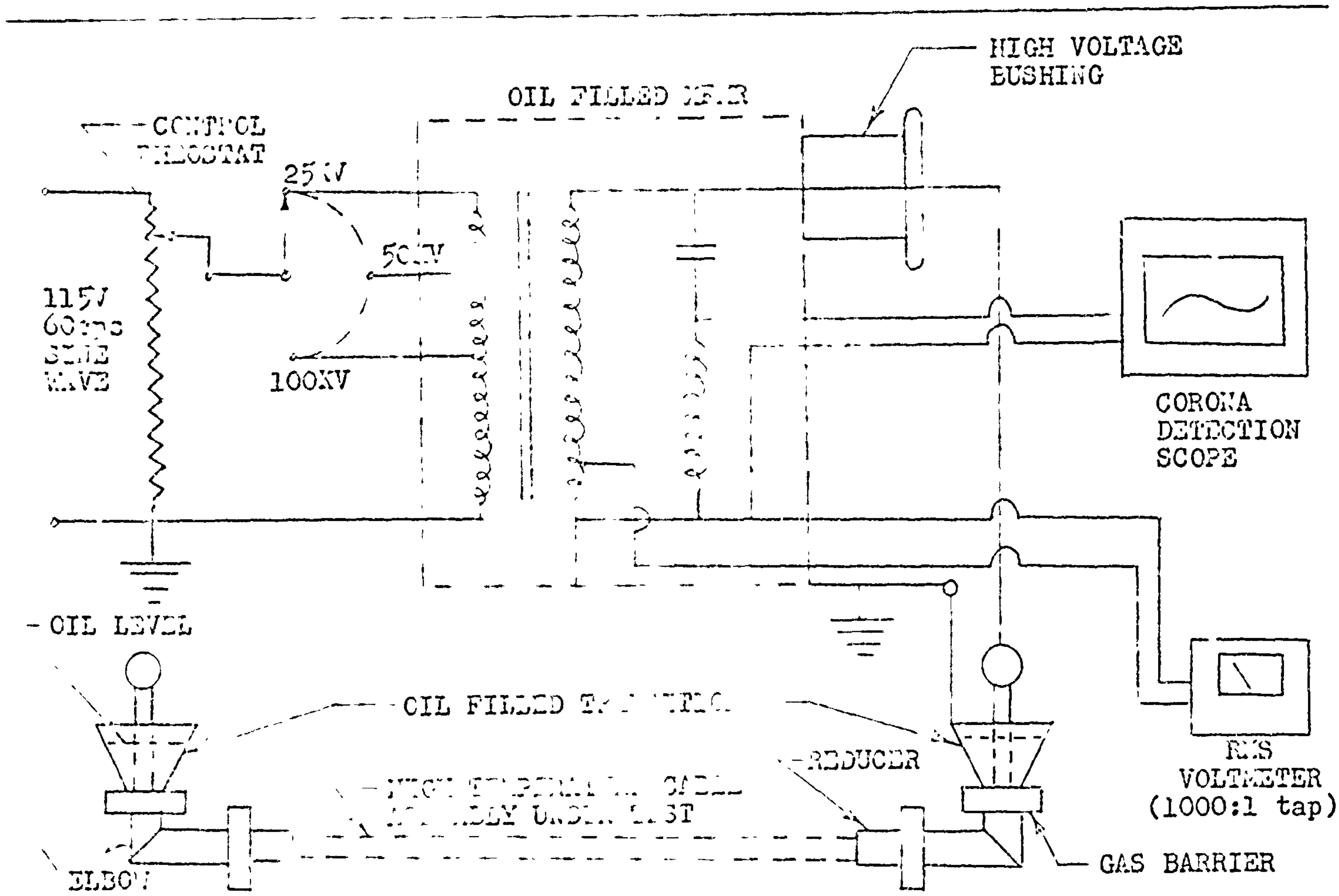


[illegible] CATEGORY	[illegible]	NO. REQ'D
Continuity Checker	S[illegible] 260	1
[illegible] Device	([illegible] source)	–
[illegible]	[illegible]	[illegible]
[illegible] Chamber	[illegible] -175-1000	1

REFERENCE

MIL-C-17D par 4.6.4, 4.6.6
J-C-98 Met 1

DIELECTRIC STRENGTH AND CORONA MEASUREMENTS



TEST EQUIPMENT CATEGORY	TYPE	NO. REQ'D
100KV Corona Tester	Davenport XCT-101	1
Oil Filled Transition	Andrew Lab.	2
Coaxial Gas Barrier	Andrew Co. 1262A	2
Coaxial Miter Elbow	Andrew Co. 1062M	2
Coaxial Reducer	Andrew Co. 1861 Andrew Co. 1860 Andrew Lab. 7/8" to 3/8"	2 2 2

FIGURE [illegible]

CABLE "B"

Contact Resistance Test

Type 347 S.S. Connector

Oven Temperature 350°C

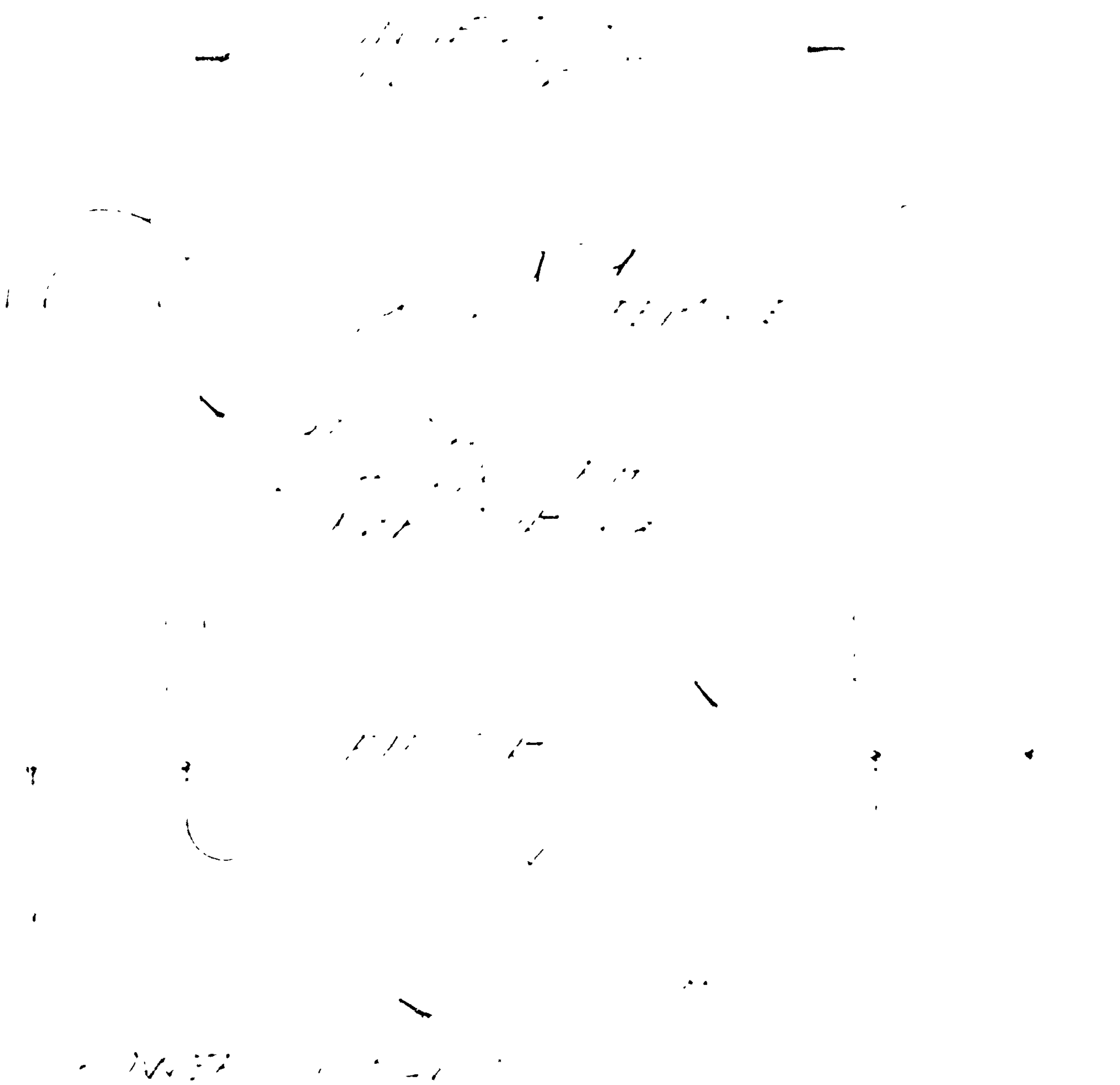


FIGURE 142

CABLE A

Vibration Test Cable

Expansion Bend

FIGURE 143

CABLE B

Vibration Test Cable

Expansion Bend

FIGURE 144

Figure 145.

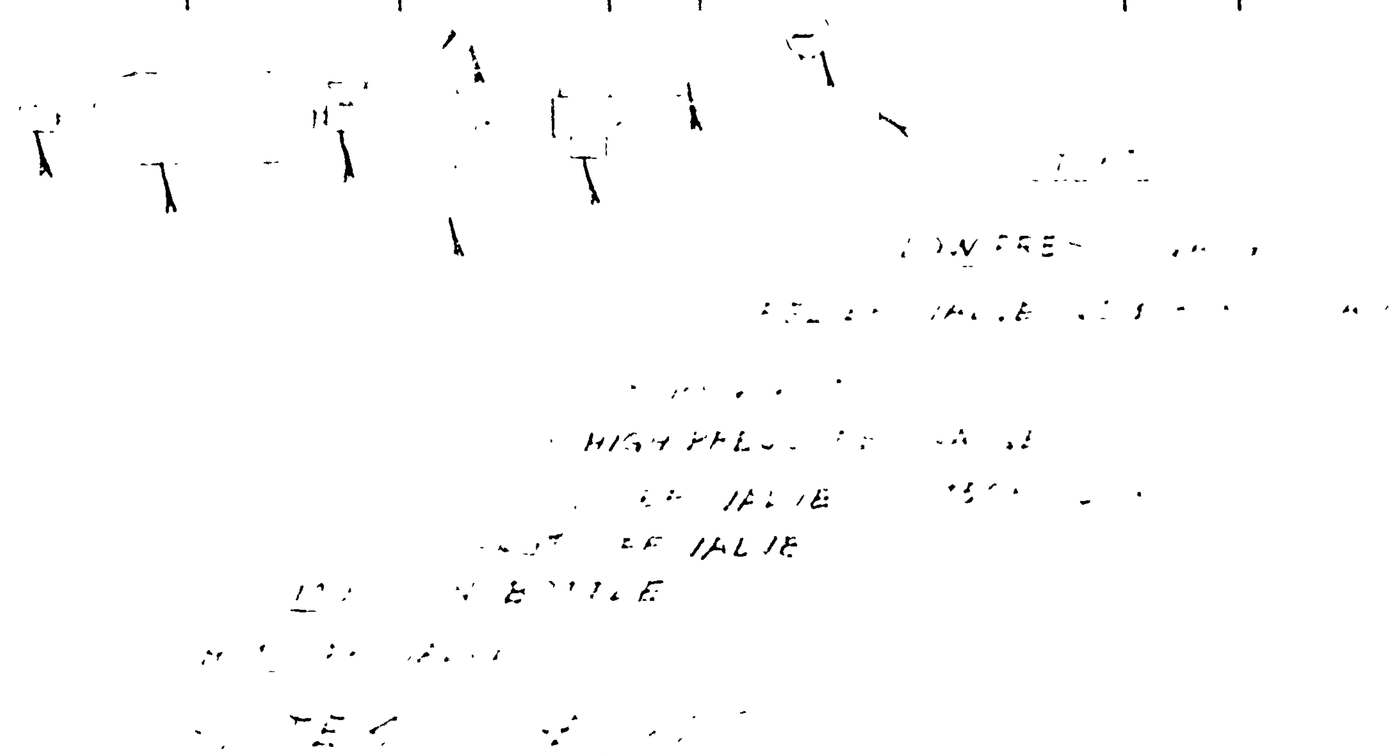
VIBRATION TESTS

Test Equipment Category	Type	
"Speaker" Type Vibrator	Webcor Testing Laboratories	See Fig. 29
Continuity Checker	Simpson 260	
Pressure Gauge	Andrew	
Cable Clamps	Type 321 S.S. Loop Type with Glass filled teflon insert	See Fig. 28

Figure 146.

Pressure Regulating System

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	SYM	DESCRIPTION	DATE	APPROVAL



NOTES:

1. The pressurizing accessories shall be suitable for applications for use in the temperature range -65 to 71°C. (160 °F)
2. The pressurizing equipment must meet the general requirements for equipment used in air-borne applications in accordance with specification MIL-E-5272A.
3. The pressure regulator is to be of the "gauge pressure" type and is to maintain 6 PSIG + 1.
4. Pressure gauge on low pressure side to indicate line pressure from 30 in. hg. vac to 150 PSIG.
5. The relief valve is to be adjustable from 65 PSIG to 135 PSIG - cracking type.
6. These accessories shall be as small and light as possible.
7. The other parts of the system are as indicated on Stewart-Warner Corp., South Wind Division, Drawing No. 47200-003-01, Rev. B.

REMOVE ALL BURRS AND SHARP EDGES | SUPERSEDES DWG OF | SHEET | DISTR

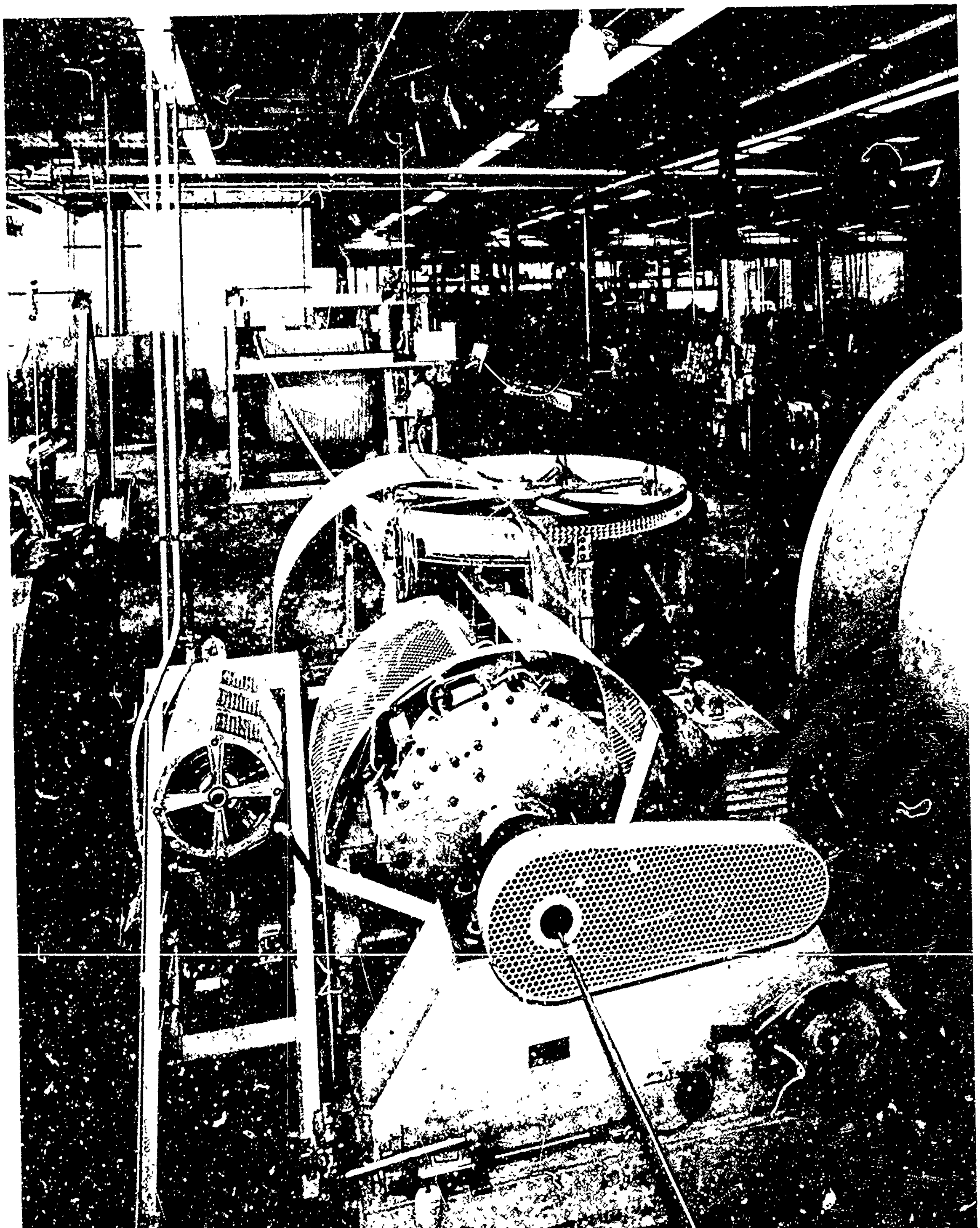
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
FRACTIONS DECIMALS ANGLES
± ± ±
ALL SURFACES
MATERIAL
FINISH

DRAWN BY | DATE | TITLE
ENGR APPD
PROD APPD

SCALE
WT CALC ACTUAL

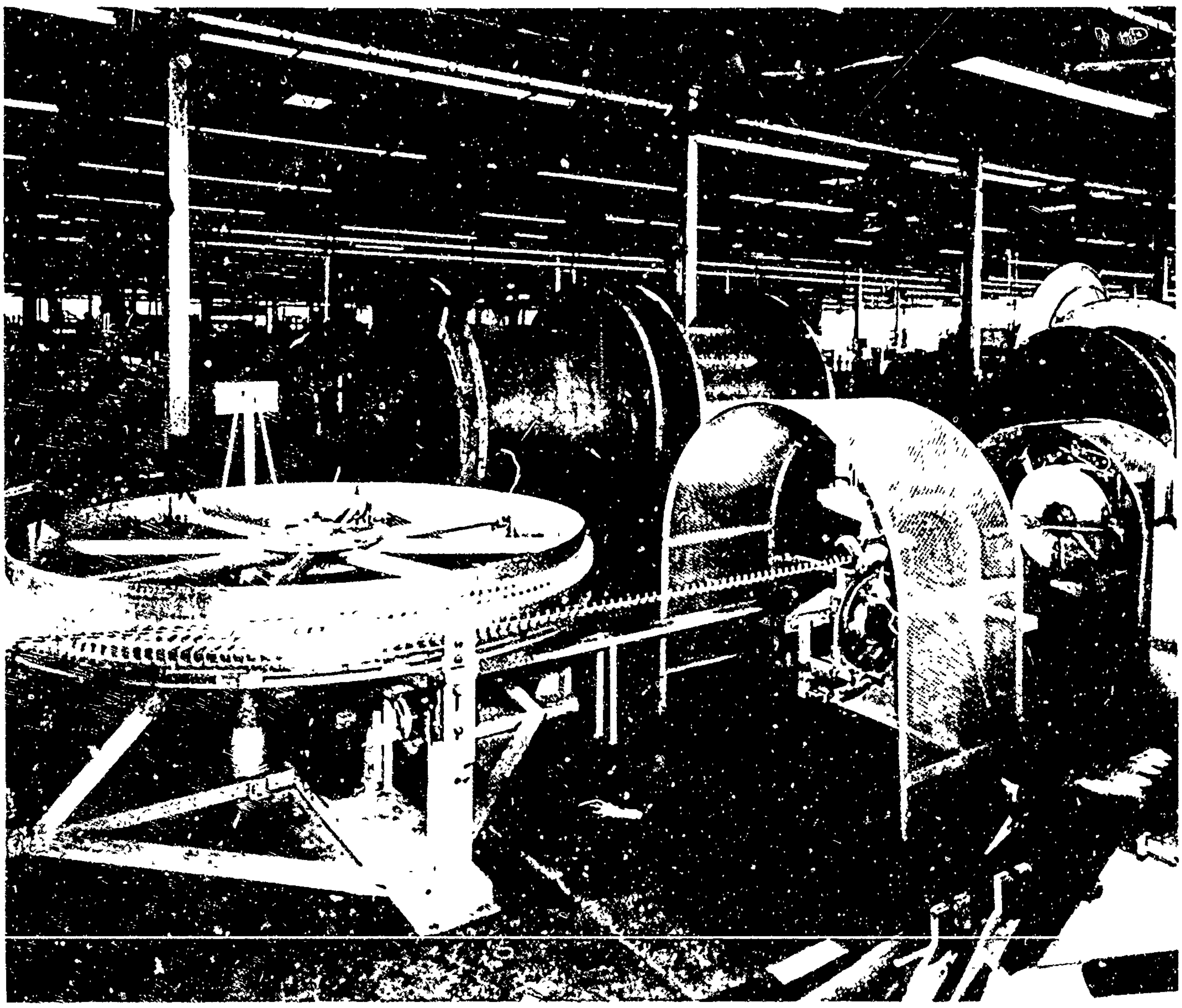
SIZE A | DWG NO 28165

Figure 147.



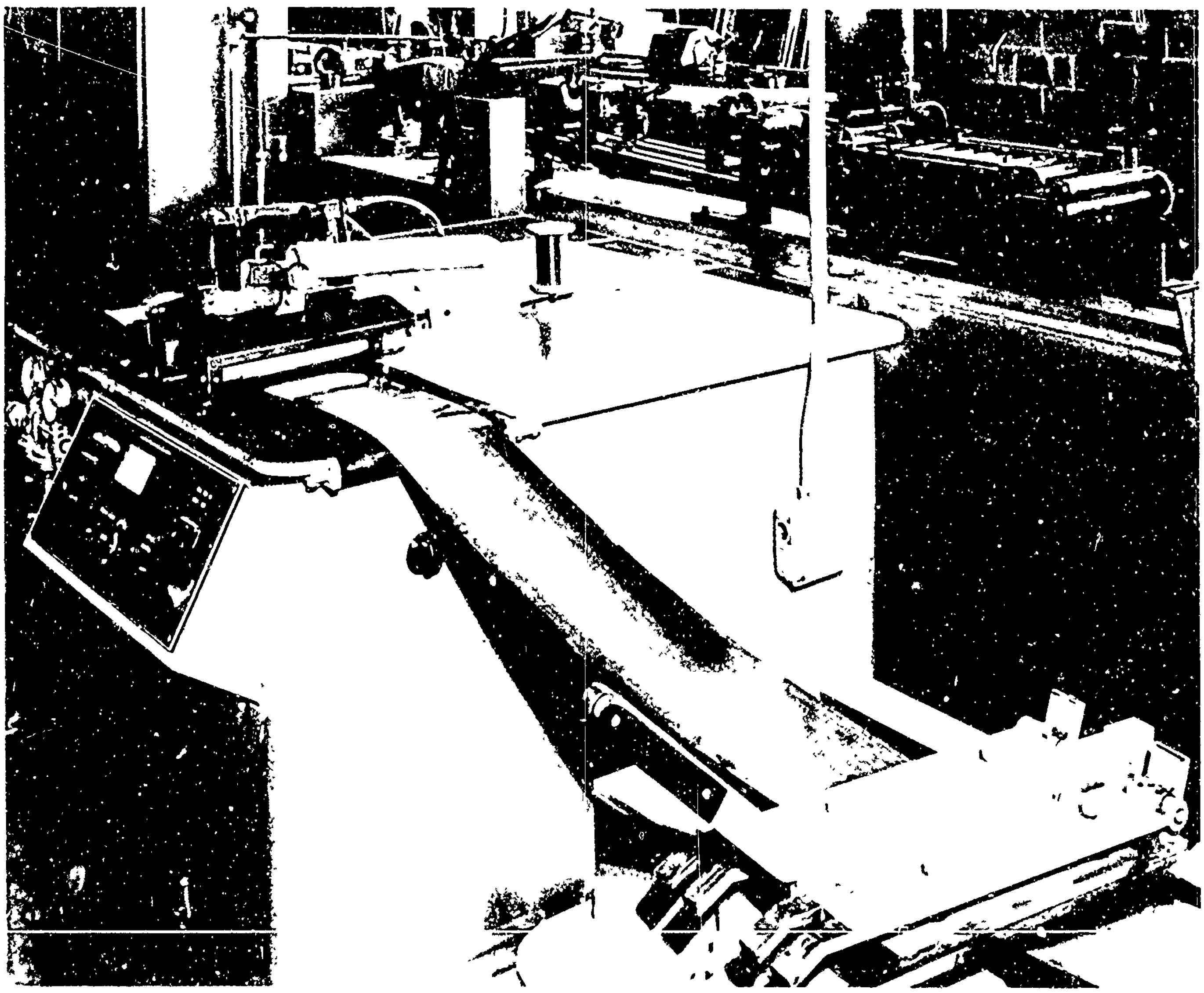
INNER CONDUCTOR TAPING MACHINE AND TAKEUP REEL

Figure 148.



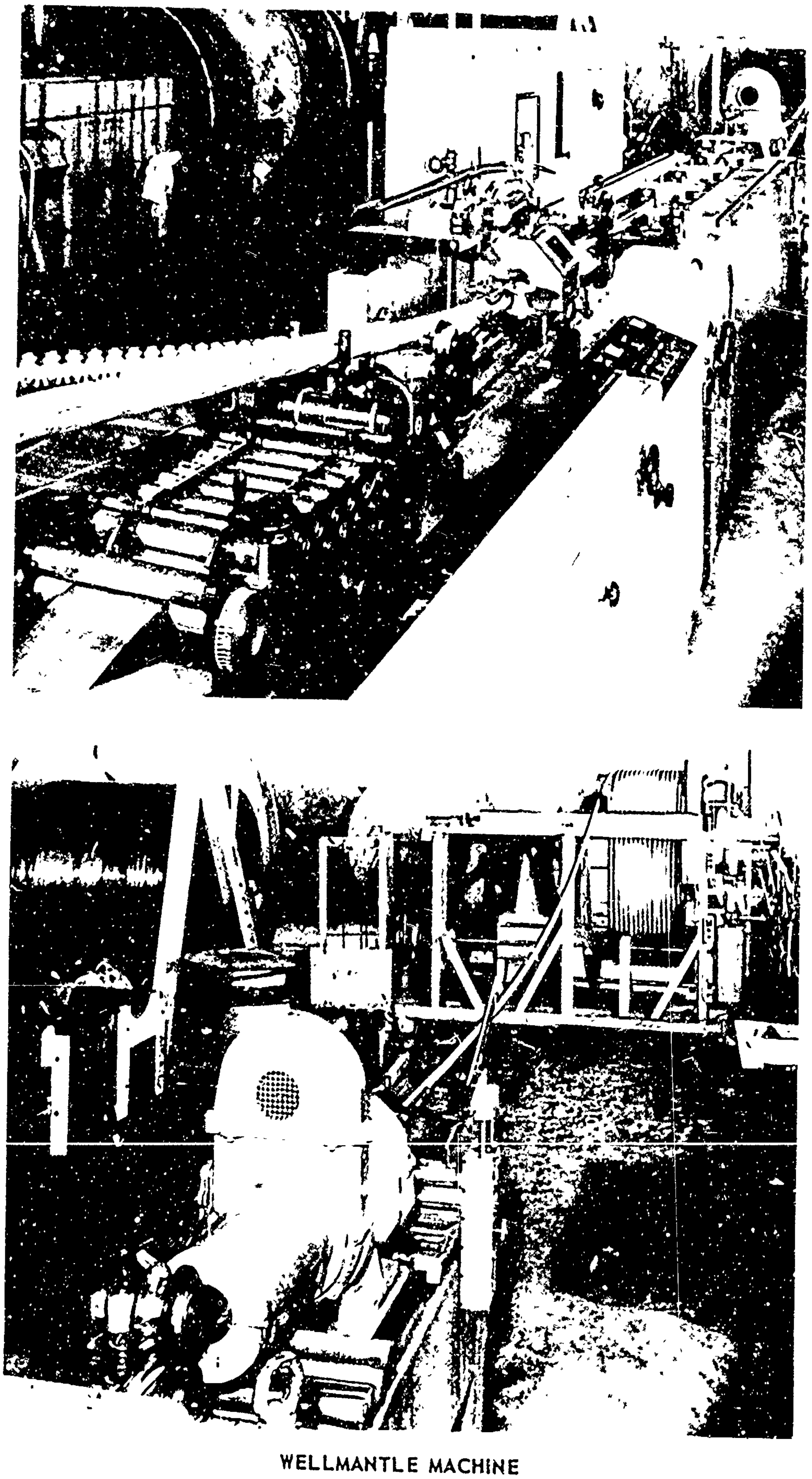
INNER CONDUCTOR TAPING MACHINE

Figure 149.



STRIP WELDING MACHINE

Figure 150.



WELLMANTLE MACHINE

Figure 150a.

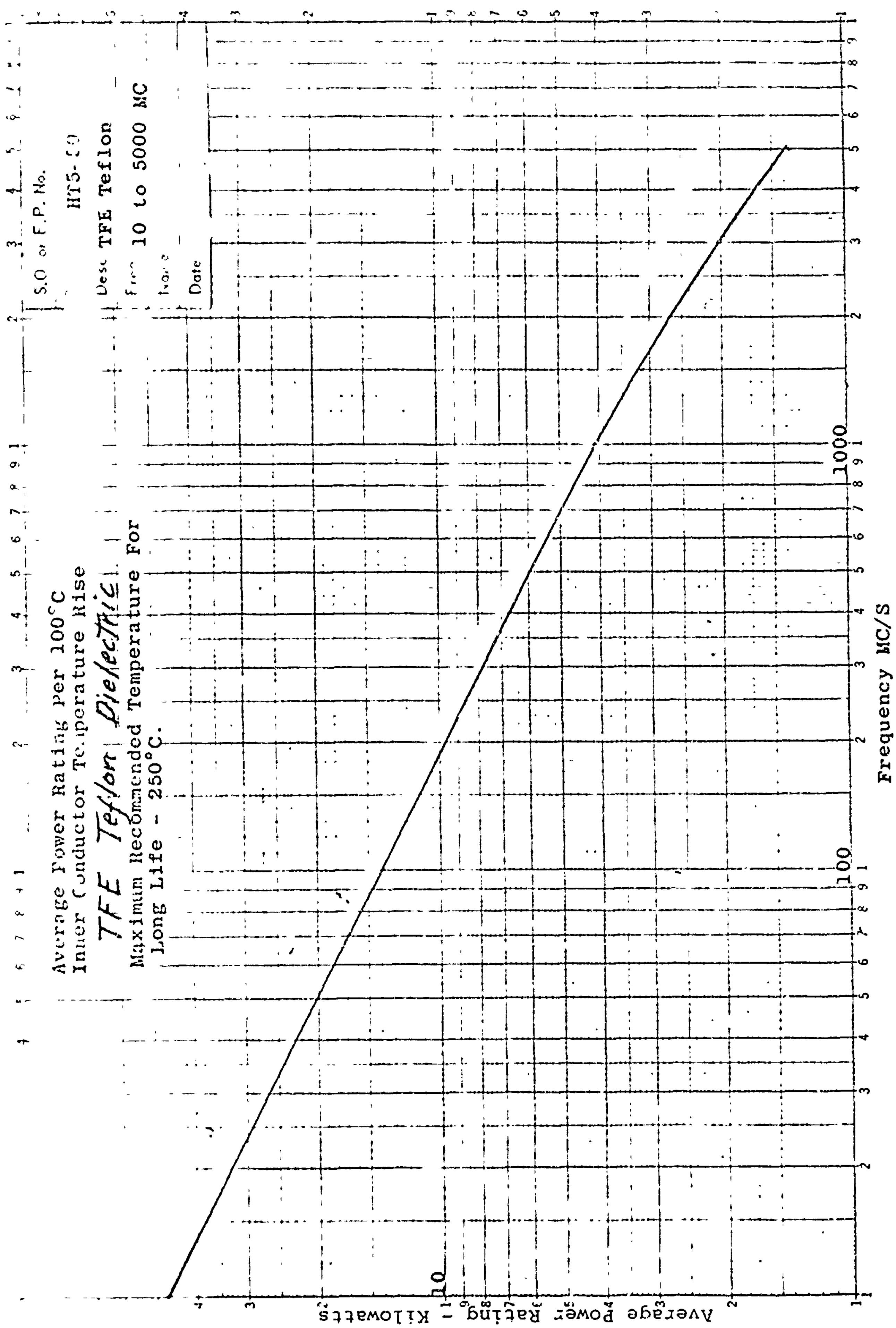
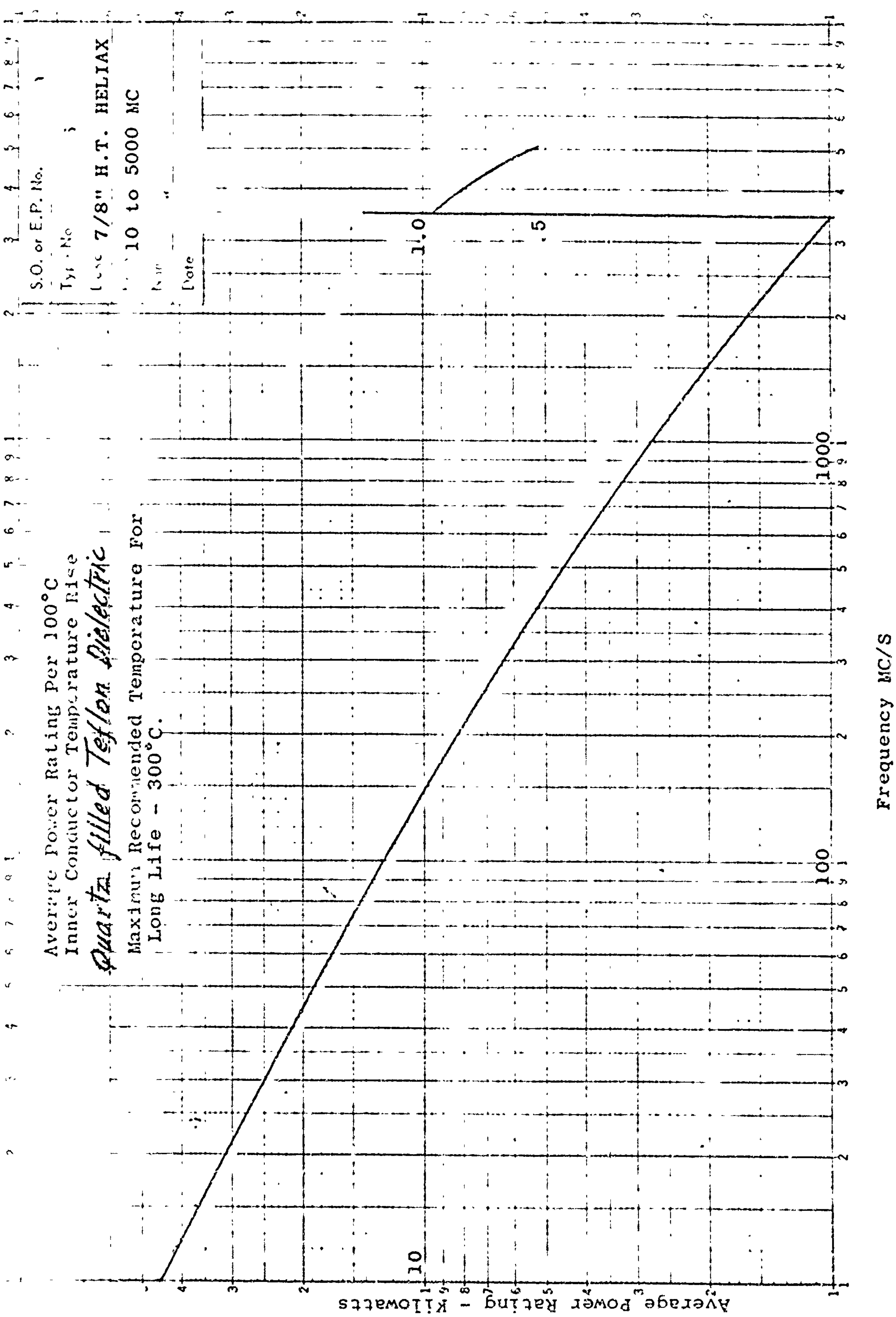

S.O. or F.P. No.
Desc TFE Teflon
10 to 5000 MC
Date
Average Power Rating Per 100°C
Inner Conductor Temperature Rise
TFE Teflon Dielectric
Maximum Recommended Temperature For
Long Life - 250°C.
Frequency MC/S
100
1000
10
Average Power Rating - Kilowatts

Figure 150 b.



Average Power Rating Per 100°C
Inner Conductor Temperature Rise
Quartz filled Teflon Dielectric
Maximum Recommended Temperature For
Long Life - 300°C.
S.O. or E.P. No.
Typ. No
7/8" H.T. HELIAX
10 to 5000 MC
Date
1.0
.5
10
100
1000
Frequency MC/S
Average Power Rating - Kilowatts

Figure 151.

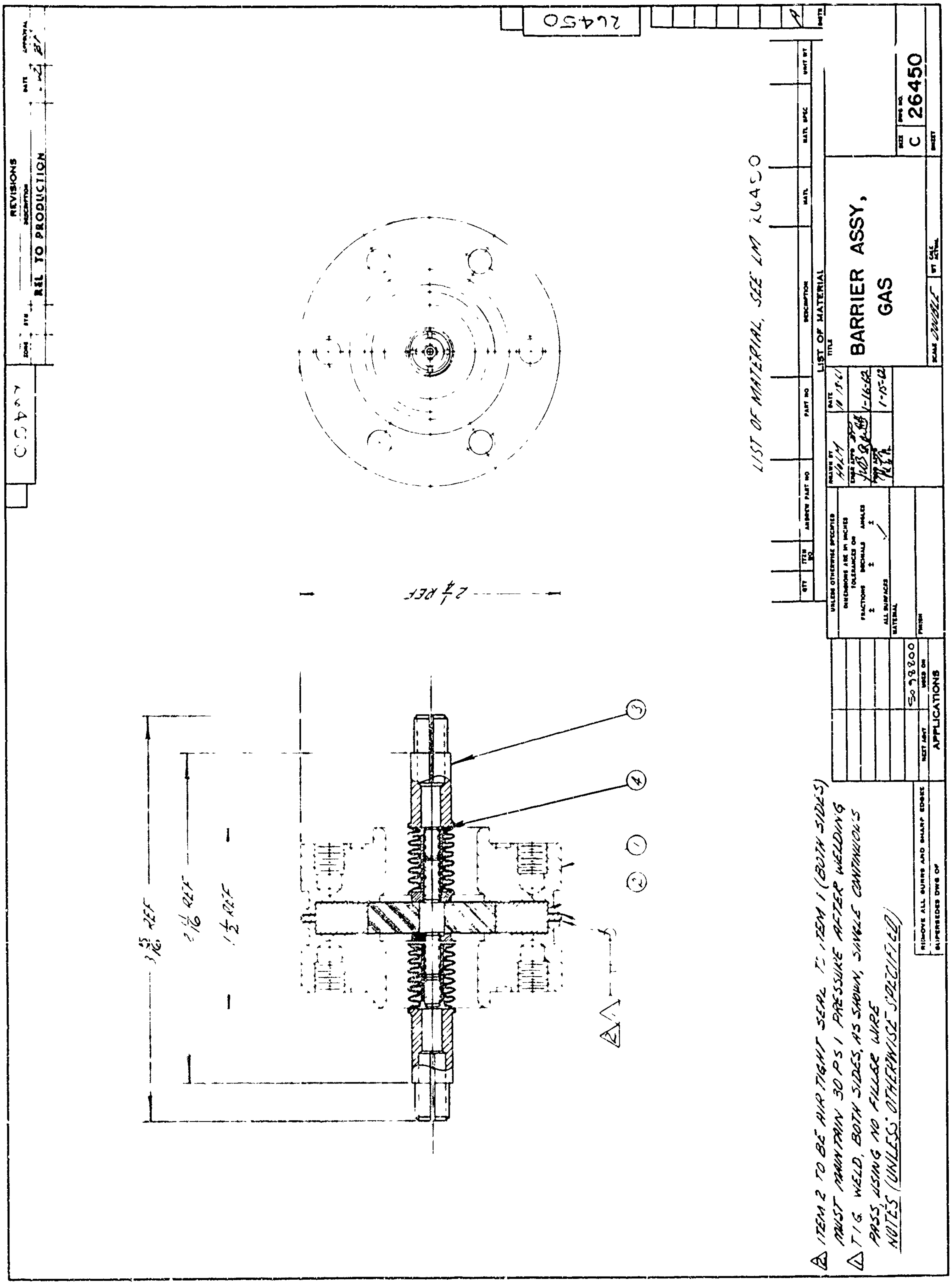
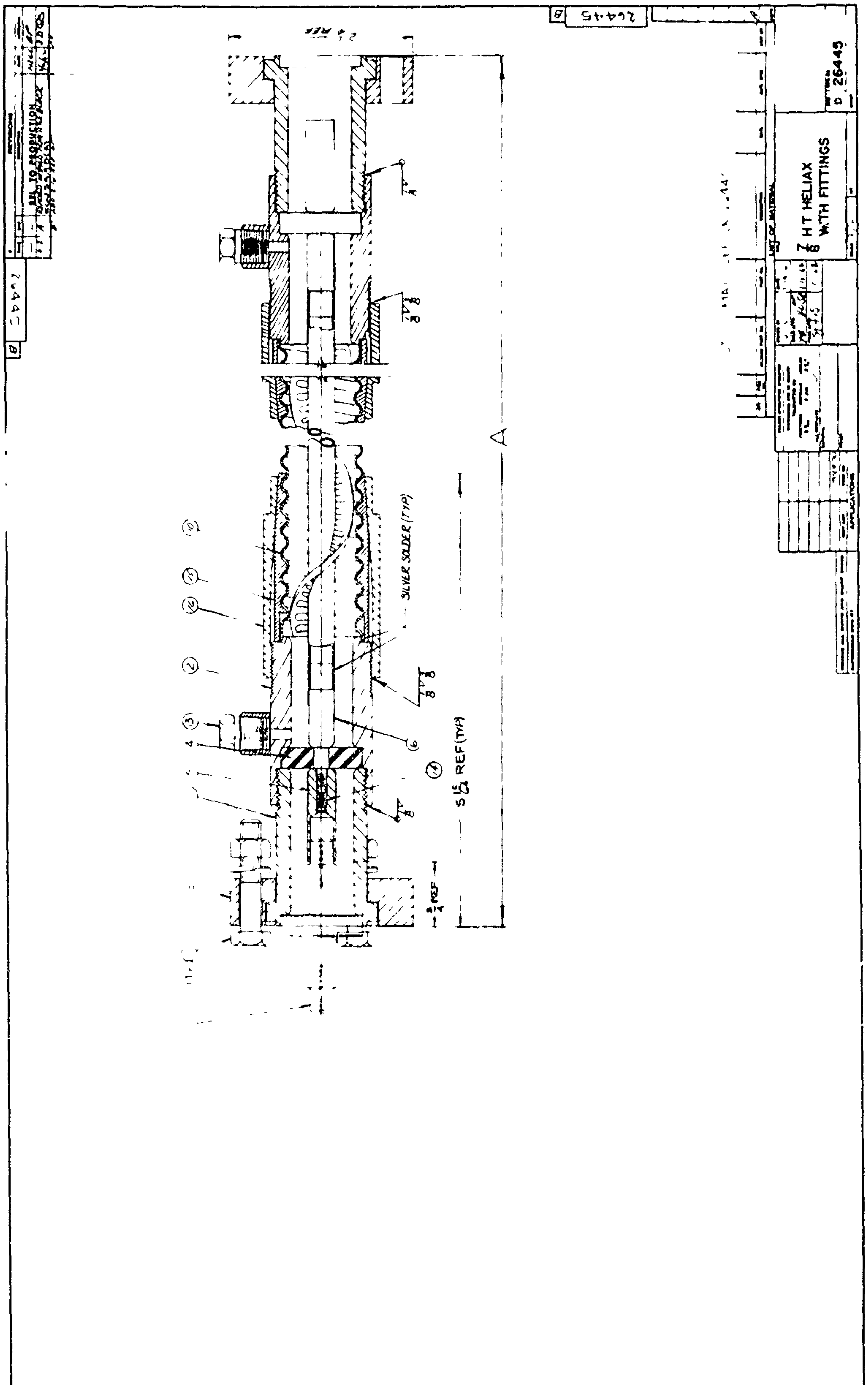
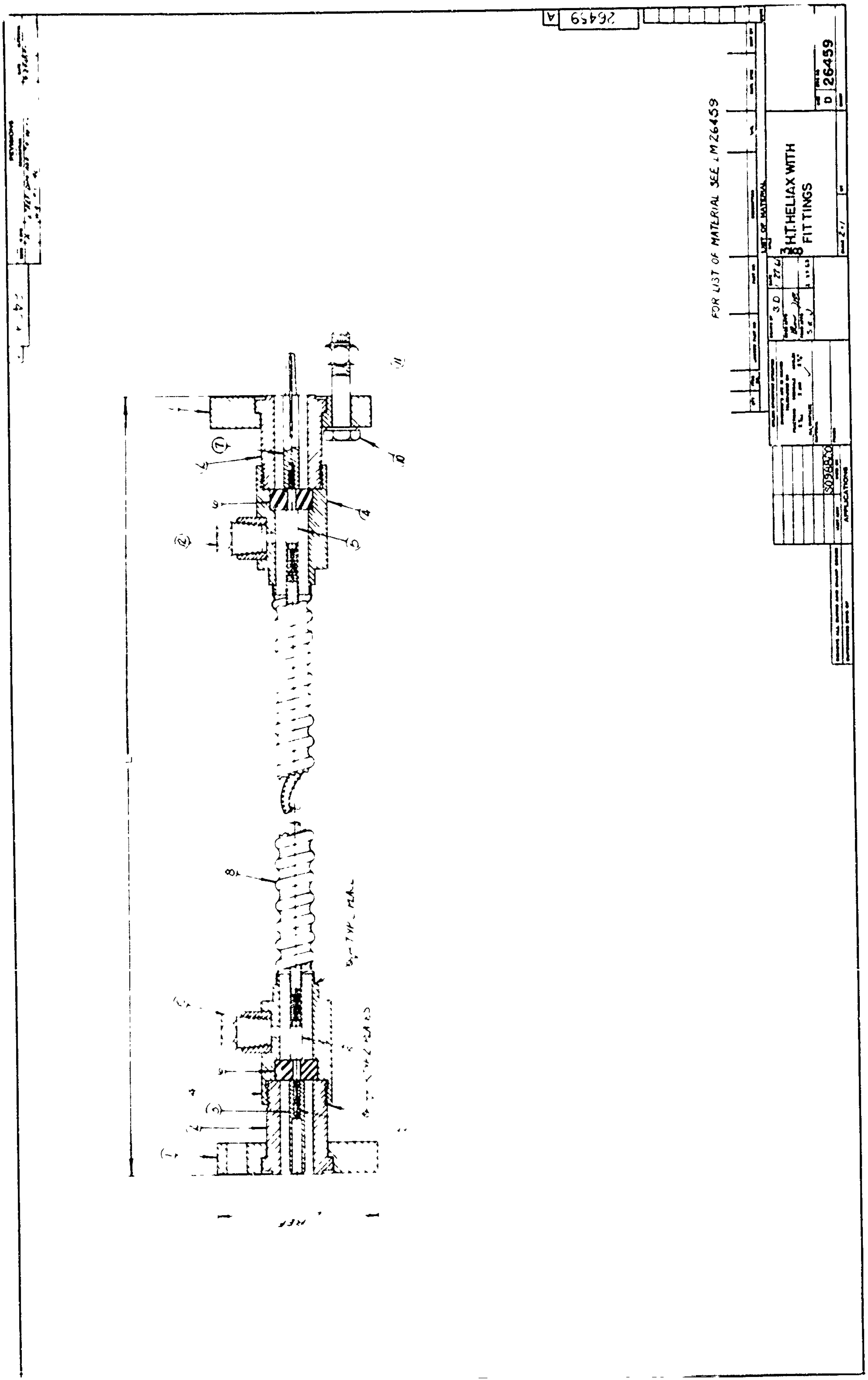

REVISIONS
REL TO PRODUCTION
26450
LIST OF MATERIAL, SEE LM 26450
LIST OF MATERIAL
BARRIER ASSY, GAS
C 26450
APPLICATIONS
$3\frac{15}{16}$ REF
$2\frac{1}{16}$ REF
$1\frac{1}{2}$ REF
$2\frac{1}{4}$ REF
1 ITEM 2 TO BE AIR TIGHT SEAL TO ITEM 1 (BOTH SIDES) MUST MAINTAIN 30 PSI PRESSURE AFTER WELDING
2 T.I.G. WELD, BOTH SIDES, AS SHOWN, SINGLE CONTINUOUS PASS USING NO FILLER WIRE
NOTES (UNLESS OTHERWISE SPECIFIED)

Figure 152.



7/8 H T HELIAX WITH FITTINGS
D 26445
SILVER SOLDER (TYP)
A
REF (TYP)
REVISIONS
LIST OF MATERIAL
APPLICATIONS

Figure 153.



26459 A
FOR LIST OF MATERIAL SEE LM 26459
3/8 H.T. HELIAX WITH FITTINGS
D 26459

PROTOTYPE CABLES

TEMPERATURE RANGE	SIZE NOMINAL	DIELECTRIC CORE	INNER CONDUCTOR		OUTER CONDUCTOR	
			MATERIAL	O.D. INCHES	MATERIAL	O.D. INCHES
65 TO 350° C	7/8"	QUARTZ-FILLED TEFLON	SILVER/OFHC	.350	SILVER/OFHC	1.00⁻
00 TO 825° C	3/8"	REFRASIL	SILVER/NICKEL/ INCONEL	.162	SILVER/INCONEL	.500⁻

HORT CABLE LIFE: −65° TO 350° C
ONG CABLE LIFE: −65° TO 300° C

Figure 1[illegible]3a

Figure 154.

ELECTRICAL CHARACTERISTICS

TEMPERATURE RANGE	CHARACTERISTIC IMPEDANCE OHMS	DIELECTRIC CONSTANT AVERAGE	CAPACITANCE MMF / FT	DIELECTRIC STRENGTH VOLTS	VELOCITY %
* −65 TO 350° C	50 Ω	1.21	22.1	14 KV (RMS) FREON-116 (6 PSIG)	90.8
−100 TO 825° C	50 Ω	1.26	22.3	4 KV (RMS) FREON-14 (6 PSIG)	89

*
SHORT CABLE LIFE: −65° TO 350° C
LONG CABLE LIFE: −65° TO 300° C